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SILVER BOW CREEK

REMEDIAL INVESTIGATION FINAL REPORT
APPENDIX C, PART 1
Report

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SILVER BOW CREEK REMEDIAL INVESTIGATION
DRAFT FINAL REPORT

WARM SPRINGS PONDS INVESTIGATION
PART 1: REPORT

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PREFACE

Silver Bow Creek originates north of Butte, Montana and is a major tributary to the upper Clark Fork River. Mill tailings and other mining wastes in and near the creek contribute to substantial downstream contamination, particularly by potentially toxic elements: arsenic, cadmium, copper, lead, iron, and zinc. These elements and others were present in the mine ore and remain as by-products of the milling and smelting processes.

The history of mining in the Butte area began with the discovery of placer gold in Silver Bow Creek, in late summer of 1864. Several townsites and camps sprung up among the diggings. However, these operations were short-lived, and most of the miners left by 1869. Those who stayed began prospecting the quartz lode deposits of silver and the associated complex copper ores on the Butte Hill. Their efforts culminated in a silver rush, which began in the mid-1870's and revived the old camp. During that time world-class deposits of copper ore were identified. By 1881, Butte had become one of the nation's major mining centers; the district attained national dominance in copper mining by the mid-1890's and international prominence by the turn of the century. By 1915, Anaconda Copper Mining Company led the industry; but in 1980, in response to a depressed copper market, Anaconda closed all the underground mines and continued active mining only in the Berkeley Pit (established in 1955). In 1977, Anaconda became a subsidiary of Atlantic Richfield Company (ARCO). ARCO closed the Berkeley Pit in 1982 and the East Berkeley pit in 1983.

In addition to mining, various ore processing facilities also operated in the Butte area. The first two mills were erected in 1874 to smelt gold and silver. Ten years later, Marcus Daly, one of the founders of the Anaconda Company, built a copper smelter 27 miles west of Butte and planned the city of Anaconda. The Anaconda Smelter was moved to a new location in the city in 1900, and operated from 1903 to 1980.

The history of over 100 years of continuous mining and related activities changed the area's natural environment greatly. Early mining, milling, and smelting wastes were dumped directly into Silver Bow Creek and transported downstream to the Clark Fork River. In 1911, the first treatment pond was built by Anaconda Company near Warm Springs, Montana, to settle out wastes from Silver Bow Creek before the water was allowed to move on. In 1916 and 1959, two more treatment ponds began operation. Silver Bow Creek continued to receive raw mining and milling wastes until 1972, when a treatment plant was added to the Weed Concentrator in Butte. Creek contamination problems were compounded by urban and domestic sewage, wood products treatment plants, phosphate and manganese production facilities, and chemical factories.

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In 1983, the U.S. Environmental Protection Agency (USEPA) designated Silver Bow Creek, contiguous portions of the upper Clark Fork River, and their environs as a high priority Superfund clean-up site. The site extends from Butte to Deer Lodge, Montana, generally following the course of Silver Bow Creek and the upper Clark Fork River. Because the various mining activities interrupted the natural flow of Silver Bow Creek, the beginning of the creek for this investigation was established as the confluence of the Metro Storm Drain and Blacktail Creek, within the city limits of Butte. The site begins at the start of the Metro Storm Drain and ends at the Kohrs Bridge north of Deer Lodge.

The Silver Bow Creek Remedial Investigation (SBC RI) project consisted of coordinated individual studies to develop data on the extent and severity of contamination within the site. Results of the studies are reported in several volumes. A Summary Final Report discusses the entire project; final reports for each individual study have been issued as appendices to the Summary, as shown below:

- Surface Water and Point Source Investigation, Appendix A, Parts 1-3;
- Ground Water and Tailings Investigation, Appendix B, Parts 1-3;
- Warm Springs Ponds Investigation, Appendix C;
- Algae Investigation, Appendix D, Part 1;
- Vegetation Mapping, Appendix D, Part 2;
- Agriculture Investigation, Appendix D, Part 3;
- Macroinvertebrate Investigation, Appendix E, Part 1;
- Bioassay Investigation, Appendix E, Part 2;
- Fish Tissue Investigation, Appendix E, Part 3;
- Waterfowl Investigation, Appendix E, Part 4; and
- Laboratory Quality Assurance/Quality Control Program, Appendix F.

The Solid and Hazardous Waste Bureau (SHWB) of the Montana Department of Health and Environmental Sciences (MDHES) administered the USEPA appropriations to conduct this project. The Montana SHWB program manager was Mr. Michael Rubich. MDHES contracted with MultiTech in October 1984 to perform the SBC RI under contract No. 50341-1202503. The Project Manager at MultiTech was Mr. Gordon Huddleston.

MultiTech was assisted in the SBC RI work by Stiller and Associates of Helena and various other subcontractors. Several state and federal agencies also provided technical information and expertise, including the USEPA bioassay team, the Montana Department of Fish, Wildlife and Parks, the Montana Water Quality Bureau, and the USEPA Montana Field Office.

Information developed in the SBC RI will be used in the next phase of the project, the Feasibility Study, to evaluate options for site remediation.

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EXECUTIVE SUMMARY

The objectives of the Warm Springs Ponds (WSP) Investigation for the Silver Bow Creek (SBC) Remedial Investigation (RI) were to evaluate the extent and severity of surface-water and ground-water contamination in the WSP area, to evaluate the effectiveness of the WSP water treatment system in metals removal, and to develop other information useful in evaluating future remedial options for this part of the SBC CERCLA site. Data collected from December 1984 to August 1985 provided the basis for evaluating the removal efficiencies of metals and for identifying the principal metals removal and release mechanisms occurring within the WSP system during a typical year.

Federal drinking water standards for the pollutants of primary interest - arsenic, cadmium, copper, iron, lead, zinc - generally were not exceeded during the RI, neither in discharges from the Warm Springs Ponds to the upper Clark Fork nor within the ponds. The four-day (chronic) aquatic life criteria for cadmium, copper, lead, and zinc and the one-hour (acute) aquatic life criteria for zinc were exceeded occasionally throughout the WSP area. The acute aquatic life criteria for copper was usually exceeded within the pond system but was not exceeded in discharges to the upper Clark Fork. Waters of the Mill-Willow Bypass exhibited chronic aquatic life toxicity with respect to copper and zinc concentrations and acute aquatic life toxicity with respect to copper concentrations.

Silver Bow Creek and the Opportunity Ponds surface discharges are the principal sources of contaminants into the WSP system. The majority of the sulfate, copper, iron, lead, and zinc loads into the Clark Fork over the entire RI study period were from the Pond 2 discharge. Although the Mill-Willow Bypass contributed only one percent of the total flow to the upper Clark Fork, it significantly degraded the water quality of the river, providing over ten percent of the cadmium, iron, and sulfate loads during the RI.

The Warm Springs Ponds treatment system is partially circumvented during extreme flow events for relatively short periods. However, these episodes are probably significant in terms of relative metals and sediment loads delivered to the Clark Fork.

Ground water downgradient of the Warm Springs Ponds and the Opportunity Ponds was contaminated, frequently exceeding Federal drinking water standards for arsenic, fluoride, iron, and sulfate. This contaminated plume extends at least one-half mile downstream of the Warm Springs Ponds, but since no domestic wells are in this area, no apparent or immediate threat to public health exists. No measurable effects of contaminted ground-water inflow to the Clark Fork River were found during the RI. Ground water from both the Opportunity Ponds and the WSP areas are the main sources of contaminant inflow to the Mill-Willow Bypass.

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An evaluation of the remaining useful life of the WSP treatment system indicates that incoming sediment loads are the principal controlling factor and that the life of the pond system could exceed 100 years under existing operating conditions. The Warm Springs Ponds sediments have some of the highest concentrations of toxic metals found anywhere in the SBC RI study area. As possible sources of contamination, these sediments pose a long-term potential threat to the water quality of the Clark Fork River.

The metals-removal efficiencies of the WSP system during the RI exhibited seasonal variations which were consistent with earlier studies. During the RI study period, overall removal efficiencies were about 87% for cadmium, 73% for lead, 65% for copper, 61% for zinc, 58% for iron, and 35% for arsenic. During the summer months the ponds showed high metals removal efficiencies primarily due to low input rates and higher pH. The drop in pH experienced during the winter months allowed more dissolved cadmium, copper, and zinc to pass through the ponds without being precipitated, resulting in lower metals removal efficiencies. Higher flows during the spring significantly lowered pond efficiencies for most metals by delivering higher contaminant loads and decreasing residence times.

Suggested remedial measures to improve the overall performance of the pond system include better pH control within the ponds (between 8.0 and 9.0 s.u.) and design changes to reduce the possibility of bypass events at lower flows. Recommendations are made to determine the significance of algal effects on pH within the ponds. Additional RI studies to further delineate the extent of contaminated groundwater in the WSP area and measurements to quantify the significance of pond bypass events also are recommended.

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1.0 INTRODUCTION

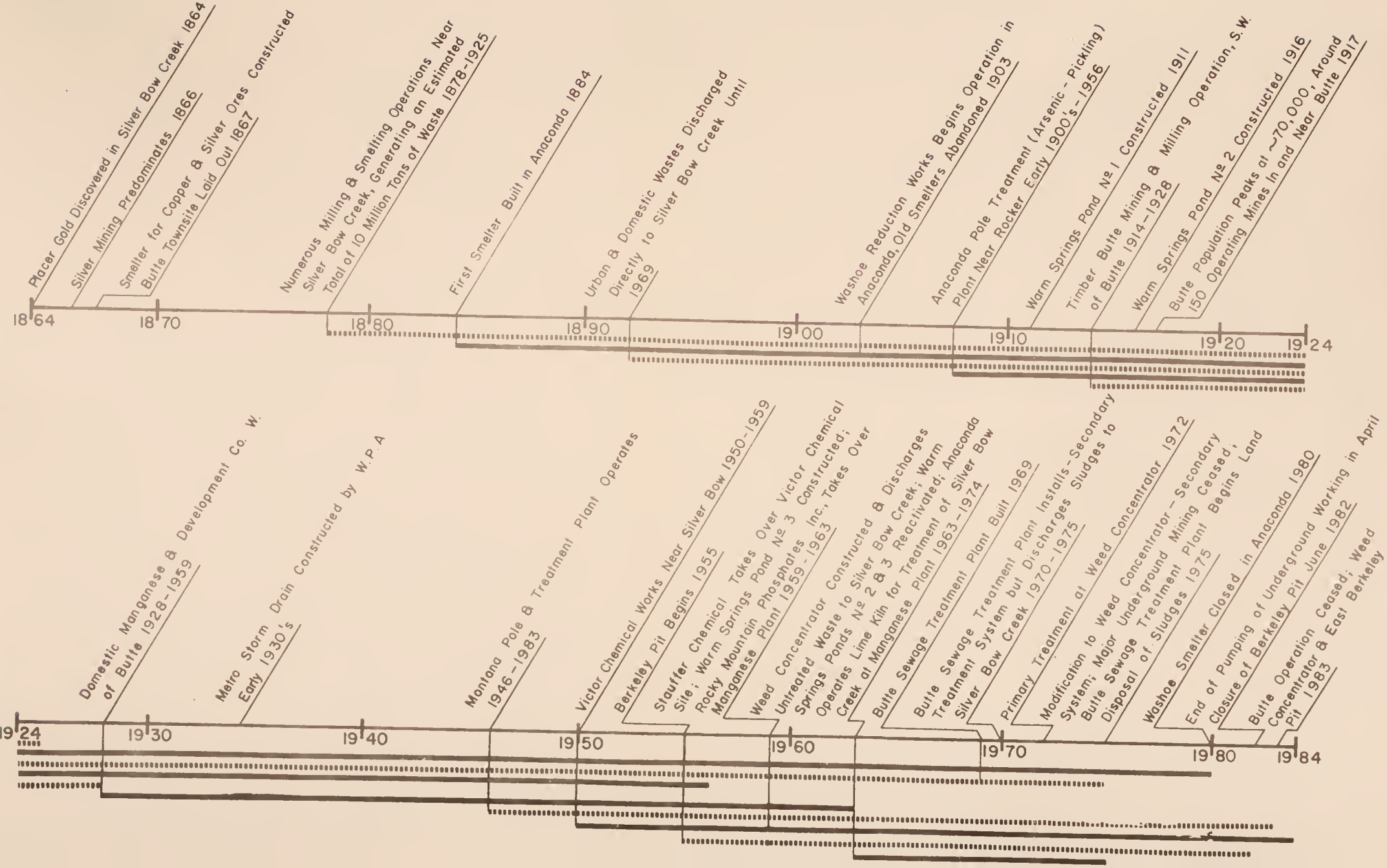
The objective of the Silver Bow Creek Remedial Investigation (SBC RI) is to determine the extent and severity of contamination within the Silver Bow Creek/Upper Clark Fork River system (Map 1-1). Once the extent and severity of contamination within the site has been determined, the risk to humans can be assessed, and feasibility studies to develop remedial actions can be completed.

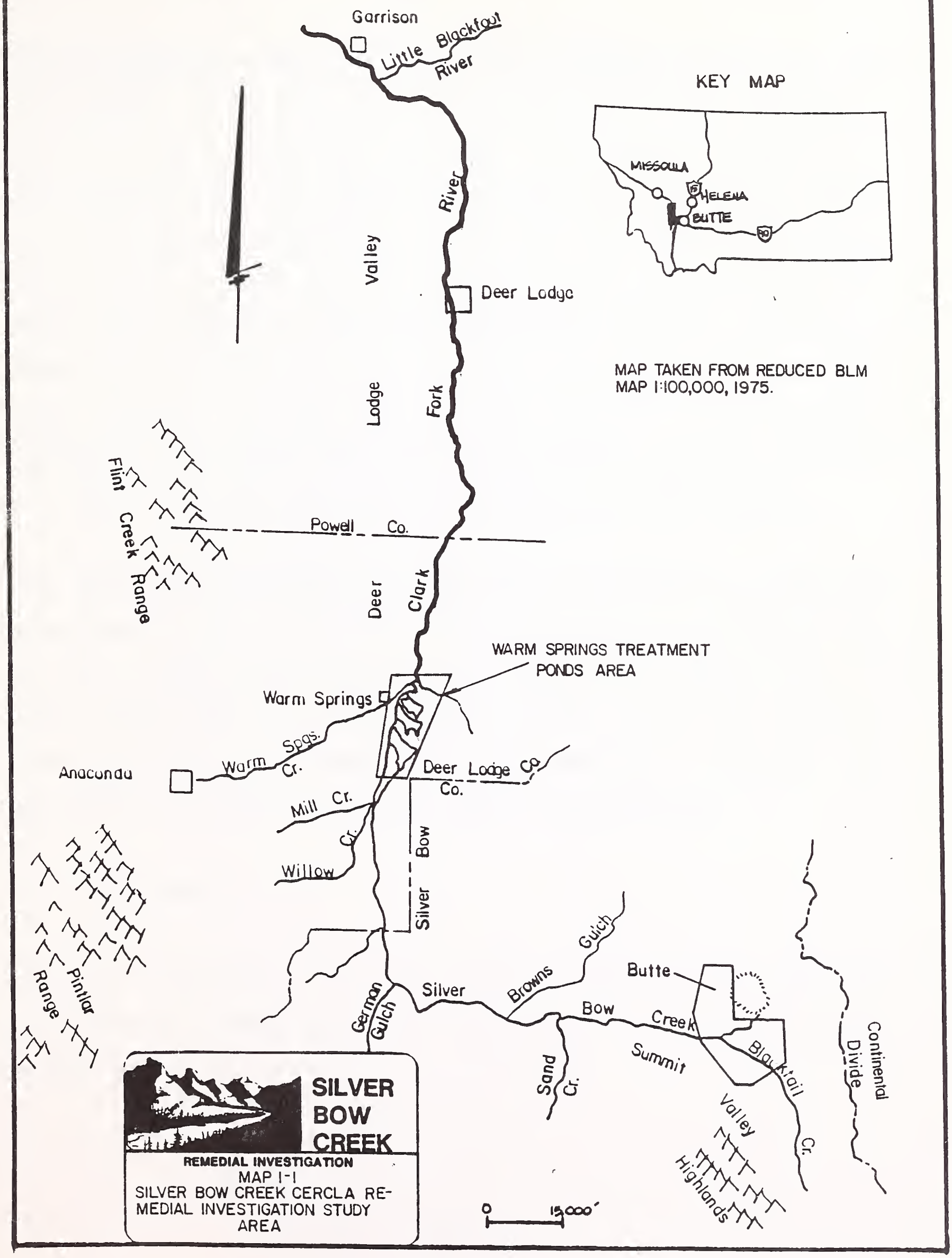
The SBC RI Warm Springs Ponds (WSP) Investigation was designed and implemented to develop new data that could be used in conjunction with existing data, (1) to describe the extent and severity of surface water and ground-water contamination in Silver Bow Creek and the upper Clark Fork River and (2) to assist in the evaluation, selection, and design of remedial alternatives. This report is the result of the investigation.

The Silver Bow Creek system has been contaminated by over 100 years of mining and smelting activities within the basin. A timeline showing significant historical events that impacted Silver Bow Creek and the upper Clark Fork River is shown in Figure 1-1. Although mining activities were suspended in this area during the RI, several possible sources still exist for continued water quality degradation of the system: tailings deposited in, and adjacent to, the surface waters; inflow of contaminated ground water; point-source discharges; and input from natural sources.

FIGURE 1-1

HISTORIC CONTAMINATION OF SILVER BOW CREEK


Placer Gold Discovered in Silver Bow Creek 1864
Silver Mining Predominates 1866
Smelter for Copper & Silver Ores Constructed
Butte Townsite Laid Out 1867
Numerous Milling & Smelting Operations Near Silver Bow Creek, Generating an Estimated Total of 10 Million Tons of Waste 1878-1925
First Smelter Built in Anaconda 1884
Urban & Domestic Wastes Discharged Directly to Silver Bow Creek Until 1969
Washoe Reduction Works Begins Operation in Anaconda, Old Smelters Abandoned 1903
Anaconda Pole Treatment (Arsenic - Pickling) Plant Near Rocker Early 1900's - 1956
Warm Springs Pond № 1 Constructed 1911
Timber Butte Mining & Milling Operation, S.W. of Butte 1914-1928
Warm Springs Pond № 2 Constructed 1916
Butte Population Peaks at ~70,000, Around 150 Operating Mines in and Near Butte 1917
1864
1870
1880
1890
1900
1910
1920
1924
Domestic Manganese & Development Co. W. of Butte 1928-1959
Metro Storm Drain Constructed by W.P.A. Early 1930's
Montana Pole & Treatment Plant Operates 1946-1983
Victor Chemical Works Near Silver Bow 1950-1959
Berkeley Pit Begins 1955
Stauffer Chemical Takes Over Victor Chemical Site; Warm Springs Pond № 3 Constructed; Rocky Mountain Phosphates Inc., Takes Over Manganese Plant 1959-1963
Weed Concentrator Constructed & Discharges Untreated Waste to Silver Bow Creek; Warm Springs Ponds № 2 & 3 Reactivated; Anaconda Operates Lime Kiln for Treatment of Silver Bow Creek at Manganese Plant 1963-1974
Butte Sewage Treatment Plant Built 1969
Butte Sewage Treatment Plant Installs Secondary Treatment System but Discharges Sludges to Silver Bow Creek 1970-1975
Primary Treatment at Weed Concentrator 1972
Modification to Weed Concentrator - Secondary System; Major Underground Mining Ceased; Butte Sewage Treatment Plant Begins Land Disposal of Sludges 1975
Washoe Smelter Closed in Anaconda 1980
End of Pumping of Underground Working in April Closure of Berkeley Pit June 1982
Butte Operation Ceased; Weed Concentrator & East Berkeley Pit 1983
1924
1930
1940
1950
1960
1970
1980
1984


Garrison
Little Blackfoot River
Deer Lodge
Valley
River
Lodge
Fork
Powell Co.
Flint Creek Range
Deer
Clark
KEY MAP
MISSOULA
HELENA
BUTTE
MAP TAKEN FROM REDUCED BLM MAP 1:100,000, 1975.
WARM SPRINGS TREATMENT PONDS AREA
Warm Springs
Anaconda
Warm Spgs. Cr.
Deer Lodge Co.
Co.
Mill Cr.
Willow Cr.
Silver Bow
Pintlar Range
German Gulch
Silver
Browns Gulch
Butte
Bow Creek
Sand Cr.
Summit
Blacktail Cr.
Valley
Highlands
Continental Divide
0
15000'
SILVER BOW CREEK
REMEDIAL INVESTIGATION
MAP 1-1
SILVER BOW CREEK CERCLA REMEDIAL INVESTIGATION STUDY AREA

The Warm Springs Ponds are treated as a separate study area from the Surface Water and Point Source Investigation (Appendix A) and the Ground Water and Tailings Investigation (Appendix B), although the ponds are identified as Area IV in the interim reports for these two investigations (Stiller and Associates 1985) (Multi-Tech and Stiller and Associates 1985). The Warm Springs Ponds were built as an effort to treat the contaminated water from Silver Bow Creek, and therefore they are a unique component of the SBC study area. However, the Warm Springs Ponds are part of the contiguous flow of surface water from Butte to Deer Lodge, and are influenced by upstream activity and influence downstream water quality.

The study area of the Warm Springs Ponds Investigation extends from the upper pH station on Silver Bow Creek (SS-19) to the discharge at Pond 2 (PS-12) and includes the Mill-Willow Bypass. Map 1-2 (Over Size) shows the Warm Springs Ponds study area, sampling sites, and associated geomorphic and hydrologic features. The period of the study was December 1984 to January 1986.

1.1 OBJECTIVES

Specific objectives of the Warm Springs Ponds Investigation were described in the SBC RI Work Plan (MultiTech and Stiller and Associates 1984):

- Determine the spatial and temporal variations in surface-water quality and quantity;

- Determine the effectiveness of the ponds in removing metals from the inflow water, the processes involved, and the expected operating life of the pond system.

- Determine interrelationships of surface and ground waters in the area and how they affect downstream resources.

The spatial and temporal variations of surface-water quality and quantity indicate the sources, transport, and fate of metals in the system. Water quality variations during major precipitation events are particularly important in identifying sources of metal contamination that reach the Clark Fork via the surface pathway. Another important contaminant pathway is ground water, and a major effort in this investigation was identifying possible effects of the ponds on ground water. The data collected help determine the relative importance of the two pathways, and thereby will aid in the selection of remedial alternatives.

Primarily, the following metals were studied: copper, zinc, iron, lead, arsenic, and cadmium. Other parameters were measured as factors affecting the chemical behavior of metals: temperature, pH, hardness, alkalinity, total suspended solids (TSS), and sulfate. This report presents the results and interpretations of those measurements. In addition, previous studies were examined to extend the data base.

1.2 SITE DESCRIPTION

The physiography, climate, soils, geology, and hydrology of the entire Silver Bow Creek site are described in the RI Summary Report; however the Warm Springs Ponds area is described below for background information.

The Warm Springs Ponds are located at the upper (southern) end of the Deer Lodge Valley, near the historic confluence of Silver Bow and Warm Springs creeks. The area occupied by the pond system is a south-north trending valley bottom bounded to the east by moderately steep hills and to the west by glaciofluvial deposits associated with the Warm Springs Creek drainage. The Opportunity Ponds also are located west of the study area and represent a significant physiographic feature (Map 1-2, Over Size).

1.2.1 Surface Hydrology

Silver Bow Creek enters Warm Springs Pond 3 from the south. Water then is routed from Pond 3 into Pond 2 by two decant towers and into the Wildlife Ponds by syphons. Both Pond 2 and the Wildlife Ponds discharge into the Mill-Willow Bypass, an artificial channel used to convey the relatively good quality water of Mill and Willow Creeks around the treatment ponds (Map 1-2, Over Size). The confluence of the Mill-Willow Bypass and Warm Springs Creek is the start of the Clark Fork River.

1.2.2 Ground-Water Hydrology

The ground-water system in the Warm Springs Ponds area is complex owing to the heterogeneity of the unconsolidated geologic deposits in the area. Alluvium and associated aquifers are present along present-day stream channels. These deposits are thin and generally are not laterally extensive throughout the area.

Other aquifers in the area are associated with Tertiary-age valley fill and thick deposits of glacial material. Several water-bearing zones are present in this material; their occurrence is typically associated with the presence of coarse-grained units. These aquifers are probably connected hydraulically to some extent, although their interrelationships are not well documented.

The convergence of four sizable streams in the vicinity of the Warm Springs Ponds suggests a ground-water discharge area. This phenomenon is typified by shallow ground-water tables and swamps, both of which are common in the area.

No domestic wells are located in the immediate vicinity of the Warm Springs Ponds; several domestic wells are located east of the pond system but these wells are completed in bedrock units which do not appear to be directly affected by the pond system. The town of Warm Springs derives its water from a supply well constructed in unconsolidated deposits of the upper Deer Lodge Valley. This well

appears to be influenced more by the Warm Springs Creek ground-water system than by the Warm Springs Ponds.

1.2.3 Climate

The study area has a continental climate with annual precipitation averaging 13.2 inches in Anaconda. Climate in the higher mountain elevations surrounding the Warm Springs Ponds is alpine to subalpine. This climate is characterized by cold temperatures and heavy precipitation, often in the form of snow. Melting of the mountain snowpack in spring and early summer provides the majority of the surface water supply within the study area.

The Warm Springs Ponds are ice-covered during the winter months. The area occasionally experiences mid-winter thaws and subsequent high streamflows. Snow cover in the lower valleys usually melts in March to early April, with the mountain snowpack normally remaining through May and into June.

1.2.4 Geology

The Deer Lodge Valley and the upper Clark Fork River are bounded on the west by the Anaconda-Pintlar and Flint Creek ranges, which contain significant amounts of limestone. This distinct lithology is reflected in both soil character and surface- and ground-water chemistry of the Warm Springs Ponds area.

1.2.5 Soils

Soils in the area are developed primarily on valley fill sediments under grassland vegetation. Adjacent to Silver Bow Creek and the Clark Fork River, shallow gravel-textured to deep fine-grained alluvial soils have developed. Nutrient-rich, organic soils of various depths are present in low or wetland areas.

Much of the natural soil in the study area has been affected by mining wastes such as mill tailings, smelter wastes, and stream deposited tailings. Mining-related wastes are generally sandy textured, reflecting their granitic origin, and typically have high concentrations of metals and sulfide minerals. Tailings, waste rock, leach pond deposits, and smelter wastes are present at locations throughout the WSP study area. These materials are generally overlying natural colluvium or alluvium and range in thickness from less than one foot to several feet.

1.3 SITE HISTORY

From the beginning of concentrating/smelting activities in 1880 until 1911, tailings from the Butte areas were carried down Silver Bow Creek to the Clark Fork River at least as far as Milltown Reservoir (built in 1907) and probably further (Moore 1985).

The Anaconda Minerals Company (AMC) made the first attempts to control the amount of sediment in Silver Bow Creek in 1911 (Hydrometrics

1983a), when the company built a 20-feet high tailings dam on Silver Bow Creek near the town of Warm Springs and created Warm Springs Pond 1.

In 1916, another 18-feet high dam was built at Warm Springs by the AMC upstream from the first dam, creating Warm Springs Pond 2 (Hydrometrics 1983a). This dam subsequently was raised 5 feet to a total height of 23 feet during 1967-1969 (Hydrometrics 1983a). Warm Springs Ponds 1 and 2 trapped and settled out sediment from Silver Bow Creek. The primary sources of this sediment were tailings eroded from deposits upstream, in and along the Silver Bow Creek channel, and increased natural sedimentation resulting from vegetation disturbance. Some sediment also may have been contributed by overflow discharge from the adjacent Anaconda and Opportunity Ponds at the Anaconda Smelter. This water was routed into Silver Bow Creek above the ponds.

A third, and much larger, 28-feet high dam was built upstream of Pond 2 by AMC between 1954 and 1959, primarily for sediment control (Hydrometrics 1983a). This structure created Warm Springs Pond 3. The height of this dam was increased by 5 feet during 1967-1969 to a total height of 33 feet (Hydrometrics 1983a).

In 1967, Warm Springs Treatment Pond 3 was converted into a treatment facility to treat mill losses, precipitation plant spent solution from Butte Operations, and overflow from the Opportunity Ponds. Treatment consisted of introducing a lime/water suspension from the

Anaconda Smelter into Silver Bow Creek above Warm Springs Pond 3. The addition of the lime suspension raised the pH of the creek water to facilitate precipitation of heavy metals in the Warm Springs Ponds. Under certain weather and stream conditions, flocculated solids overflowed to the Clark Fork River (Spindler 1976; Hydrometrics 1983a).

1.4 PREVIOUS INVESTIGATIONS

The first published study of water quality in the Warm Springs Ponds was by Spindler (1959). This report for the Montana State Board of Health included studies of Silver Bow Creek and the upper Clark Fork River. Spindler found Silver Bow Creek to be strictly an industrial waste conduit almost devoid of life. However, he documented a recent improvement in water quality in the upper Clark Fork River which was attributed to the construction of Warm Springs Pond 3.

During the 1970's, Silver Bow Creek and the upper Clark Fork River were studied frequently. This was also a period in which AMC began efforts to clean up Silver Bow Creek, because the Warm Springs Ponds did not provide sufficient protection of the Clark Fork River (Spindler 1976). Self-monitoring data collected by the company are available from this period, some of which are described by Casne et al. (1975).

The USEPA studied the upper Clark Fork River in 1970, but did not include Silver Bow Creek in its study (USEPA 1972). This was a water chemistry, benthic, and fish study which showed a very limited biological community was present in the upper Clark Fork River. A similar conclusion was reached by Gless (1973) in a study of the upper Clark Fork drainage which included Silver Bow Creek. Gless found almost no invertebrates in Silver Bow Creek and attributed this lack to heavy metals loads and no suitable substrate.

Hydrometrics (1983a-h) completed a comprehensive study for AMC which included an analysis of historic water quality data, storm runoff sampling, ground-water sampling in the Colorado Tailings, and tailings material sampling. Beuerman and Gleason (1978) sampled Silver Bow Creek and the Warm Springs Ponds during the summer of 1977. Sulfate data are also available from a study of the upper Clark Fork River in 1978 (Botz and Karp 1979). These three studies were compared by James (1980). James and Searle (1981) evaluated factors affecting metals concentrations in the Warm Springs Ponds discharge. James and Peterson (1983) evaluated the effectiveness of Pond 2 operation within the WSP System.

The Montana Department of Health and Environmental Sciences (MDHES) Water Quality Bureau (WQB) has collected data on Silver Bow Creek and the upper Clark Fork River since the suspension of operations at the Weed Concentrator in February 1983. An intensive stream-sampling program conducted on April 27 and 28, 1983 was reported by

the department (MDHES 1983). The WQB continues to collect data on the upper Clark Fork River and around the Warm Springs Ponds as part of its Clark Fork River survey.

With the exception of studies performed since February 1983, historical water quality data for the Warm Springs Ponds do not reflect current stream conditions. The RI supplies data that describe the lasting impacts of mining in the WSP area, impacts that were partially reduced by suspension of mining in Butte. Several other data gaps in previous studies are filled by the RI:

- Very few of the earlier studies collected samples from enough stations to allow identification of contaminant sources. Since the cessation of mining at Butte Operations, only the MDHES WQB study of April 1983 provides any such data.

- Most of the studies, with the exception of the United States Environmental Protection Agency (USEPA) and Montana studies, did not analyze for dissolved metals. This lack makes identification of sources more difficult and understanding of the metal removal mechanisms nearly impossible.

- Metals analyzed in previous studies were usually limited to copper and zinc.

- None of the previous studies collected enough data to complete a mass balance analysis of the pond system.

DRAFT

2.0 METHODS

Methods employed during the Warm Springs Ponds Investigation of the Silver Bow Creek Remedial Investigation (SBC RI) are the same as those described in the SBC RI Work Plan (MultiTech and Stiller and Associates 1984). This section describes historic data evaluation, field investigation methods, and data analysis and interpretation techniques. Where methods differed from those described in the Work Plan, appropriate justification is provided.

2.1 HISTORIC DATA COLLECTION AND EVALUATION

Historic surface-water, point-source, and ground-water data were collected from several sources, such as various state and Federal regulatory agencies, published and unpublished reports, and the Anaconda Minerals Company (AMC). These data sources generally included water quality analyses, sampling locations, and other pertinent sample information.

Three review criteria were used to judge if historic surface-water and point-source data should be included in the computerized data base: (1) water quality data must have accompanying and concurrent discharge data; (2) the sampling party or agency must be identifiable; and (3) the sampling location must be identifiable.

Criteria for entering historic ground-water data in the computerized data base included the following: (1) verification of sample location and sampling agency/individual; (2) location of sampling site relative to areas of interest; (3) availability of a lithologic drilling log for the well; and (4) completion of water quality analyses by an identifiable laboratory.

The compiled historic data then were compared to U.S. Environmental Protection Agency (USEPA) criteria for data acceptance. The USEPA has two levels of Data Reliability Criteria which have separate documentation requirements. Level A criteria includes the sampling date, location, and team; sample collection, preparation, and preservation techniques; shipping and analysis dates; laboratory preparation and analytical methods; and detection limits. Level B criteria includes all the criteria listed for Level A, plus quantitative statistical control samples, chain-of-custody control documents, and proper USEPA sampling and analysis protocol.

Data which meet Level A requirements only may be used to help direct the RI study. Data meeting Level B constraints can be included with RI-generated data for evaluating risks or remedial alternatives.

Only data collected during the period 1975 to 1985 were analyzed. In 1975, the quality of Butte Operations' discharge was notably improved by modifications to the Weed Concentrator. In February 1983, the Weed Concentrator was closed due to suspension of mining

operations, and this discharge ceased. Therefore, data for the period 1975 to 1983 were analyzed separately from data collected from February 1983 to August 1985.

2.2 FIELD INVESTIGATION

The primary analytes of interest to the Warm Springs Ponds investigation are heavy metals (iron, zinc, copper, lead, cadmium, and arsenic). Parameter lists were developed initially to quantify those parameters which historically were elevated in the surface and ground water, or those which could aid in identifying hydrochemical processes occurring within the study area (Table 2-1). Analytical parameters were adjusted during the course of the RI on a site-specific basis in response to data evaluation. These adjustments were made with the approval of the Montana Department of Health and Environmental Sciences (MDHES). Field activities were performed by Stiller and Associates, of Helena, Montana.

2.2.1 Surface-Water and Point-Source Sampling

Surface-water and point-source sampling sites in the Warm Springs Treatment Ponds area were located following a review of existing water quality and quantity data and a field reconnaissance of the area. Sampling sites were located at all known inputs to the pond system, at the two discharges from the pond system, and at sites along the Mill-Willow Bypass. Locations of all sampling sites are

TABLE 2-1
SURFACE-WATER, POINT-SOURCE, AND GROUNDWATER
PARAMETER LISTS

Category I	Category II	Category III	Ground-water Parameters
Discharge	Discharge	Discharge	Static Water Level
Temperature	Temperature	Temperature	Temperature
Specific Conductivity	Specific Conductivity	Specific Conductivity	Specific Conductivity
pH	pH	pH	Eh
	TDS [a] (measured)	TDS (measured)	pH
	TSS [b]	TSS	Dissolved Oxygen
	Sulfate	Sulfate	Sulfate
	Nitrate (as N)	Nitrate (as N)	Alkalinity
	Alkalinity	Alkalinity	Copper[f]
	Hardness (as $CaCO_3$)	Hardness (as $CaCO_3$)	Arsenic[f]
	Copper [c]	Copper[c]	Zinc[f]
	Zinc [c]	Zinc[c]	Iron[f]
	Iron [c]	Iron[c]	Cadmium[f]
	Lead [d]	Lead [c]	Lead[f]
	Arsenic [d]	Arsenic[d]	Magnesium
	Cadmium [d]	Cadmium[d]	Calcium
		Orthophosphate (as P)	Sodium
		Phosphorus (total)	Potassium
			Chloride
			Fluoride

Notes:

(a) TDS - Total dissolved solids
(b) TSS - total suspended solids
(c) Total and dissolved constituents
(d) Total constitutents only
(e) Total extractable constituents
(f) Dissolved constituents only

shown on Map 1-2 (Over Size) and listed in Table 2-2. A more detailed description of site location is presented in Attachment I and a schematic diagram of the sampling sites is presented in Figure 2-1. Surface-water and point-source sampling during the RI began in December 1984 and terminated in September 1985. Sampling dates are presented in Table 2-3.

Changes to the sampling sites or schedule around the Warm Springs Ponds from those described in the RI work plan are as follows:

(1) SS-27A, a pump outfall that originates below Pond 1. This water seeps below Pond 1 and is pumped back into Pond 1. It was added as a sampling location in May 1985.

(2) PS-11A, Wildlife Ponds discharge. This site was added as a monitoring site in December 1984, at the same sampling frequency as surface-water monitoring sites. The site had been overlooked as a point-source discharge to the Mill-Willow Bypass in the Work Plan.

(3) SS-19, SS-21, SS-22, PS-11A, and PS-12. The sampling frequency at these sites was changed to semi-monthly for the period July through September 1985.

Surface-water and point-source sites in the Warm Springs Ponds area were sampled on the same day during each sampling episode, with the exceptions of stations SS-23 and SS-24 in the Opportunity Ponds.

TABLE 2-2
SURFACE-WATER AND POINT-SOURCE SAMPLE STATION DESCRIPTIONS
AND
SAMPLE ANALYTICAL CATEGORIES

Site Number(a)	Site Description	Analytical Category(b)
SS-16	Silver Bow Creek at Gregson Bridge	II
SS-19	Silver Bow Creek at upper pH shack	III
SS-23	South discharge ditch from Opportunity Ponds	II
SS-24	North discharge ditch from Opportunity Ponds	II
SS-20	Pond 3	II
SS-21	East decant tower dicharge	III
SS-22	West decant tower discharge	III
PS-11A	Wildlife Ponds discharge	III
SS-27A	Pond 1 seepage pumpback to Pond 1	II
SS-27	Pond 1 pumpback to Pond 2	II
SS-26	Pond 2	II
PS-12	Pond 2 discharge	III
SS-18	Mill-Willow Bypass at Frontage Road	II
SS-25	Mill-Willow Bypass above Pond 2 discharge	II

(a) Sample site locations are shown on Map 1-2 (Over Size).
(b) Parameters included in analytical categories are described in Table 2-1.

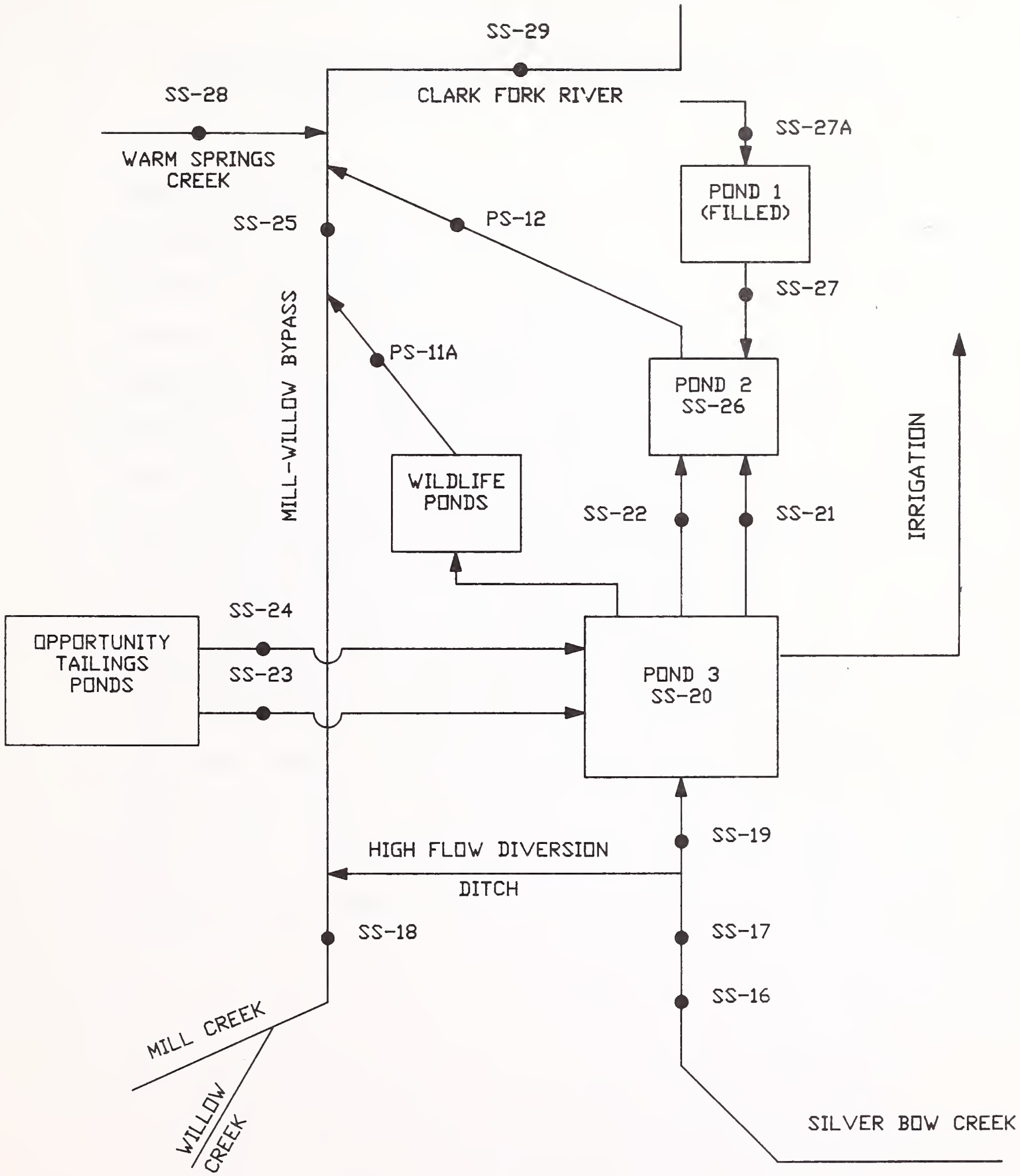


FIGURE 2-1

SCHEMATIC DIAGRAM OF WARM SPRINGS PONDS
AREA SAMPLING STATIONS (NOT TO SCALE)

TABLE 2-3
SURFACE-WATER AND POINT-SOURCE SAMPLING DATES AND CORRESPONDING SAMPLING RUN NUMBERS

Sampling Date	Run Number
December 3-5, 1984	1
December 26-28, 1984	2
January 28-30, 1985	3
February 11-13, 1985	4
February 25-27, 1985	5
March 11-13, 1985	6
March 25-27, 1985	7
April 8-10, 1985	8
April 22-24, 1985	9
May 6-8, 1985	10
May 20-23, 1985	11
June 3-5, 1985	12
June 17-20, 1985	13
July 22-25, 1985	14
August 27-29, 1985	15

These discharges occasionally were sampled the day before the other sites in the Warm Springs Ponds area.

Stream gaging was performed at appropriate sites with a Price AA or pygmy current meter. Discharge from the two pipe outfalls, SS-27 and SS-27A, were measured with a bucket and stopwatch. Other measurements made in the field were water temperature, pH, and specific conductance. Details of field measurement procedures are found in Attachment II. Field decontamination procedures were followed to avoid the contamination of samples, personnel, and equipment. Decontamination procedures used during the Warm Springs Ponds investigation are also described in Attachment II.

Water quality samples were collected from stream channels using DH-48 depth-integrated samplers. The total discharge of the stream was divided into four sections of equal discharge. Depth-integrated samples were taken at the midpoint of each section and combined in 1-gallon plastic sample containers. Pipe sources usually were sampled directly with the sample container. Pond water samples were obtained using a Kemmerer sampler. Water from the sample containers was poured into appropriately labeled bottles and preserved as required by the QA/QC plan. Dissolved constituents were filtered using 0.45 micron filters before being poured into sample bottles. Samples were tracked using taped bottle labels, laboratory analysis request forms, and chain-of-custody forms. Water samples collected in the Warm Springs Ponds were analyzed in accordance with analytical categories outlined previously.

2.2.2 Seepage Runs

Seepage runs are measurements of discharge and associated water quality obtained during baseflow or near baseflow conditions at several reaches in a stream. By measuring streamflow in this manner, an analysis of the stream's influent/effluent characteristics can be completed and a better understanding of surface-water/groundwater interrelationships is attained.

Because discharge measurements are completed during baseflow conditions, the influence of factors such as runoff and stream-stage fluctuation are minimized. Inherent to a seepage run is the measurement of all tributary inputs to the stream under study so that compensation can be made for these influences.

Two seepage runs were conducted during the RI on the Mill-Willow Bypass; one was completed July 25, 1985 and the other August 29, 1985. Map 1-2 (Over Size) shows locations of sampling sites used during the seepage runs. Parameters measured during the seepage runs are presented in Table 2-4. Field parameter measurements and decontamination procedures were completed in accordance with procedures outlined in Attachment II. Water quality and discharge data from the seepage runs are contained in Attachment III.

TABLE 2-4
SEEPAGE RUN PARAMETER LIST

Discharge

Temperature

pH (field)

Specific Conductivity (field)

Sulfate

Chloride

Calcium

Magnesium

Sodium

Potassium

Alkalinity

Copper (a)

Zinc (a)

Note:

(a) Total, dissolved, and total extractable.

2.2.3 Installation of Permanent Gaging Station

A continuously recording gaging station was installed in May 1985 at site SS-19 in the Warm Springs Ponds area (Map 1-2 Over Size). The recorder at this site was connected to the natural stream channel, as shown by a typical installation in Figure 2-2. Stage was determined using a float and pulley connected to an Omnidata electronic recorder, which uses an erasable, programmable read-only memory chip (EPROM) for storage of data. Data were read using an Omnidata detapod reader and stored on computer for analysis.

A staff gage was installed in the channel in the vicinity of the continuously recording gage. The staff gage was mounted on wooden beams supported by iron pipes driven into the stream bottom. The staff gage established a local datum to reference the recorder readings. The continuously recording gage was monitored during regular semi-monthly sampling runs. During these visits the stilling well was flushed, the staff gage was read, and the data recorder was checked for proper operation. A discharge measurement also was made with a current meter to determine the stage-discharge relationship.

2.2.4 Pond Bottom Sediment Sampling

Bottom sediments from Ponds 2 and 3 were sampled twice during the RI. The first sampling was conducted during ice break-up on each pond; the second event occurred approximately four weeks after the

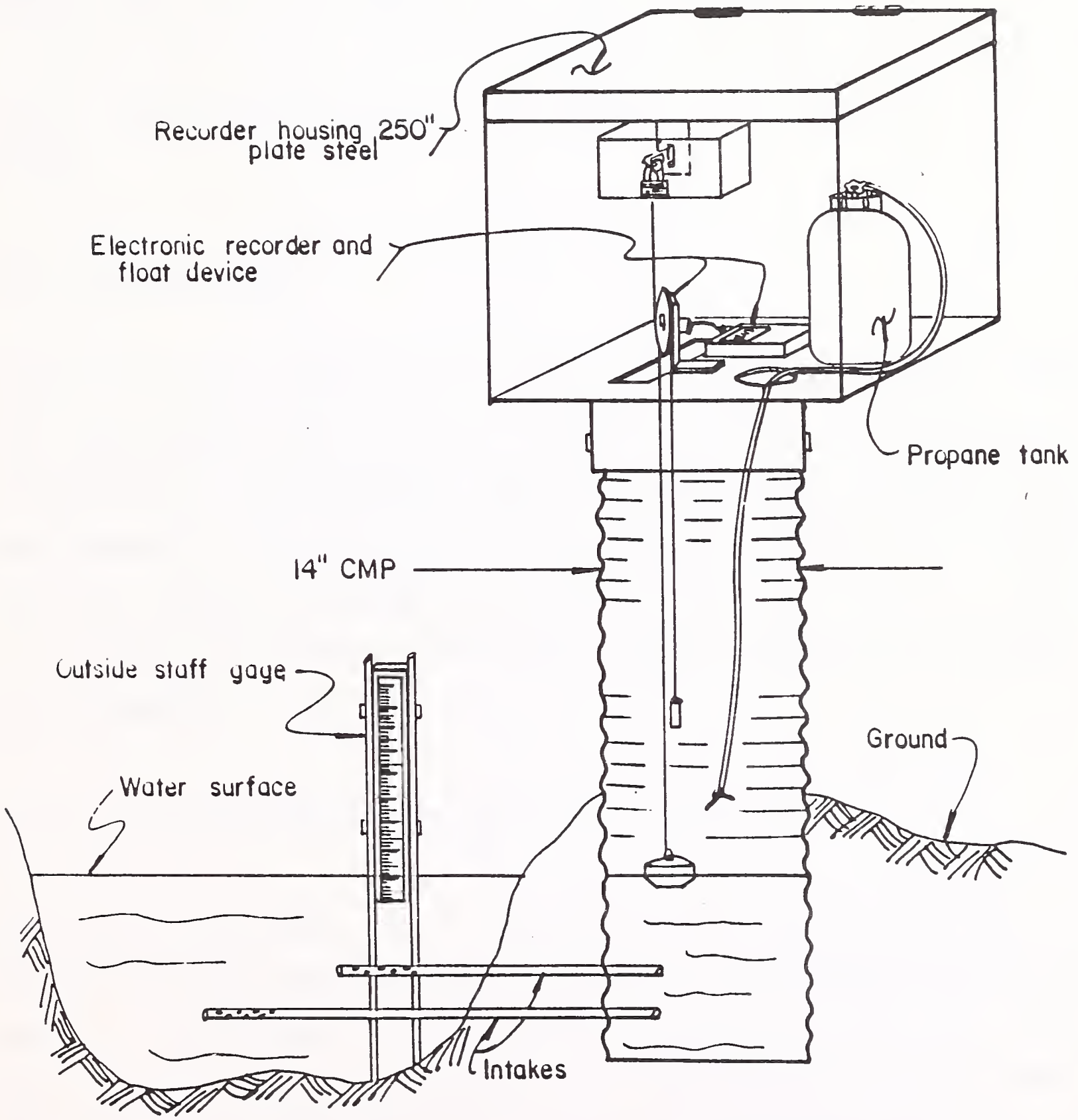


FIGURE 2-2

TYPICAL SURFACE-WATER GAGING STATION INSTALLATION

first sampling episode. Samples were obtained from three sites on Pond 2 and two sites on Pond 3, as shown on Map 1-2 (Over Size). Samples were collected using a soil auger and immediately transferred to sample containers. Field measurements were made for dissolved oxygen, redox potential (Eh), pH, temperature, and specific conductivity.

2.2.5 Ground Water

The ground-water investigation conducted in the Warm Springs Ponds area supplemented data from the Anaconda Smelter CERCLA site and existing data. From November 1984 to November 1985, existing wells were sampled. Phase II ground-water activities began in December 1985 and included sub-surface material sampling; monitoring well installation; surveying; ground-water level monitoring; and ground-water sampling.

2.2.5.1 Drilling and Monitoring Well Installation

Five monitoring wells (WSP-1 through WSP-5), were constructed in the Warm Springs Ponds area during Phase II ground-water activities (Map 1-2, Over Size). Lithologic and completion logs for these wells are contained in Attachment IV. Two of the five wells (WSP-2 and WSP-3) were completed by installing two casings perforated at different depths in a single borehole. This dual completion technique, properly implemented, maximizes the utility of a borehole and minimizes drilling costs.

Monitoring well locations were selected to characterize ground-water conditions believed to be interacting with the Warm Springs Ponds system. Influences on the Warm Springs Ponds ground-water system from the adjacent Anaconda Smelter CERCLA site were assumed to be adequately characterized, and some of these data were available for analysis during this investigation. A corollary purpose in locating monitoring wells was to determine the downgradient extent of any subsurface contaminant migration from the Warm Springs Pond area.

A cable tool drill rig was utilized for monitoring well installations. The drill rig was decontaminated prior to setup over a hole and at the end of drilling activities. Decontamination procedures used are described in Attachment II.

A split-spoon core sampler was used during drilling activities to obtain sub-surface material samples at discrete intervals. All material sampling apparatus received appropriate decontamination between sample collection episodes in accordance with procedures described in Attachment II. Material samples were subsequently bagged and delivered to the laboratory for analysis.

The general drilling procedure involved churning material with the cable tool and bailing cuttings with a sand bailer. This material was logged by an on-site hydrogeologist; selected samples were bagged and archived for future reference. Six-inch steel casing was driven into the boring to minimize borehole collapse. The

lower 2 feet of the steel casing was perforated, which allowed sampling water from discrete intervals. The collected water samples were promptly analyzed for field parameters. This procedure proved valuable in determining poor-quality zones in the ground-water system and in identifying perforated intervals and total depths for monitoring well casings.

Single well construction was completed at WSP-1, WSP-4, and WSP-5 in the Warm Springs Ponds area. The construction consisted of placing decontaminated 4-inch, schedule-40, flush-threaded PVC casing into a 6-inch borehole. The casing installed was factory-slotted in the zone(s) of interest. Chemically inert silica sand was placed between the steel casing and PVC and adjacent to the perforated interval.

The steel casing was pulled back in sections by utilizing hydraulic jacks and/or the drill rig to expose the PVC casing to the borehole. A mixture of bentonite and pea gravel was used to backfill the annular space about the PVC above the perforated interval. The steel casing was pulled completely out of each hole and the well annulus was sealed with cement overlying bentonite. A locking well protector was installed over the PVC casing. Figure 2-3 depicts the final single-well design utilized during the investigation.

Dual completion monitoring wells were constructed at boreholes WSP-2 and WSP-3. This procedure was similar to that described for single-well construction except that two 2-inch, decontaminated PVC

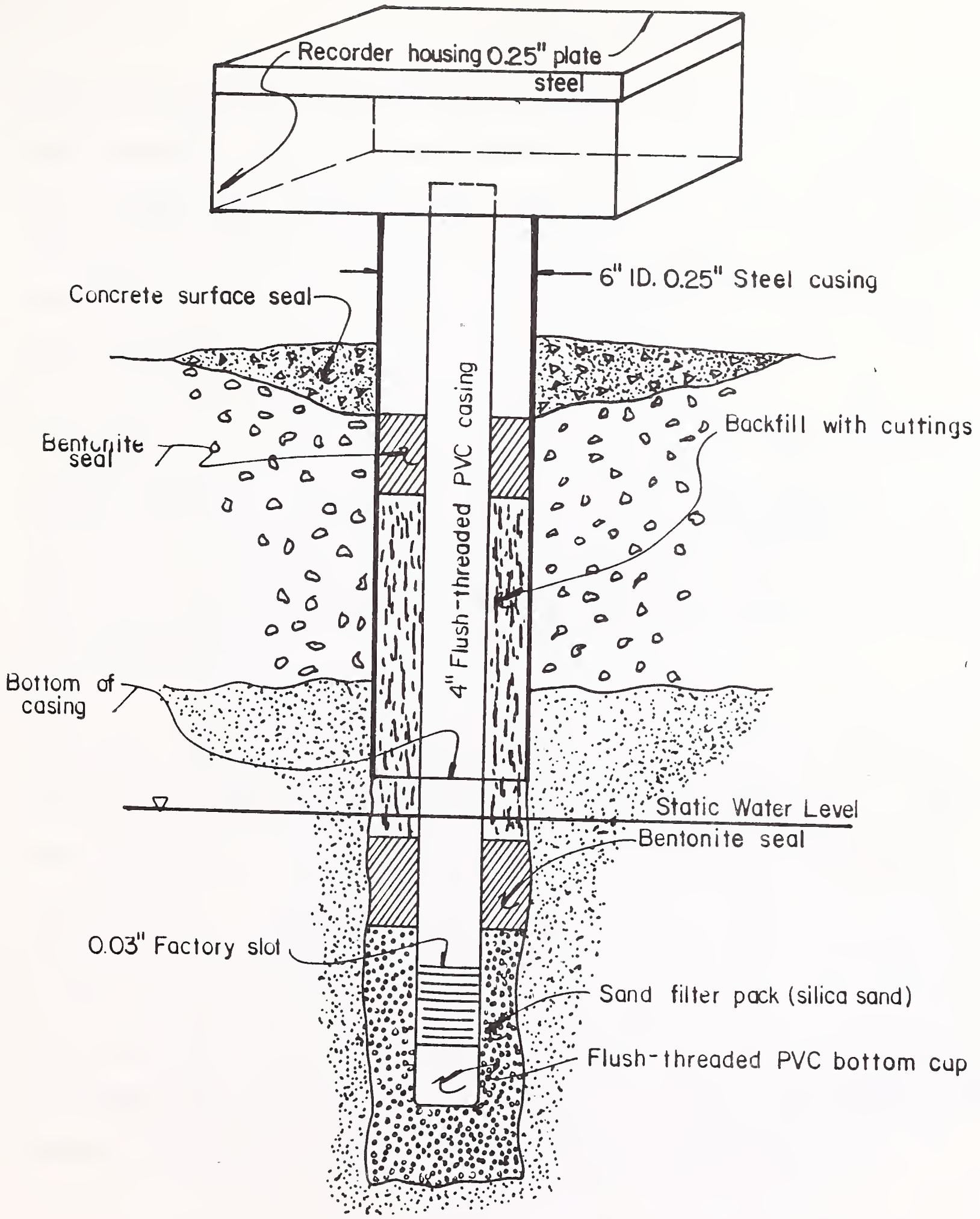


FIGURE 2-3

TYPICAL SINGLE MONITORING WELL CONSTRUCTION

casings, perforated at different depths, were installed in the 6-inch borehole. The interval between the perforated sections of the two casings was packed with bentonite to establish hydraulic separation between the two water-bearing zones. Figure 2-4 is a schematic of the dual completion monitoring well design used during this investigation.

All monitoring wells constructed during the RI were developed to remove drilling debris from the borehole. Development also was performed to enhance the effectiveness of the sand pack around the perforated portion of the casing in bridging fine-grained sediment out of the well.

The well development technique involved surging with compressed air using a 100 cfm (cubic feet per minute) air compressor. This air was directed into the monitoring wells through a hose, which was connected to a perforated PVC pipe placed in the well. Water in the wells was evacuated intermittently using this technique for a period of time until the discharge appeared clean and essentially sediment free. Decontamination procedures used for well development equipment are described in Attachment II. Well development field forms are contained in Attachment IV of this report.

2.2.5.2 Water Level Measurement

Static water levels were measured in various existing wells in the Warm Springs Ponds area periodically during 1985 and in Phase II

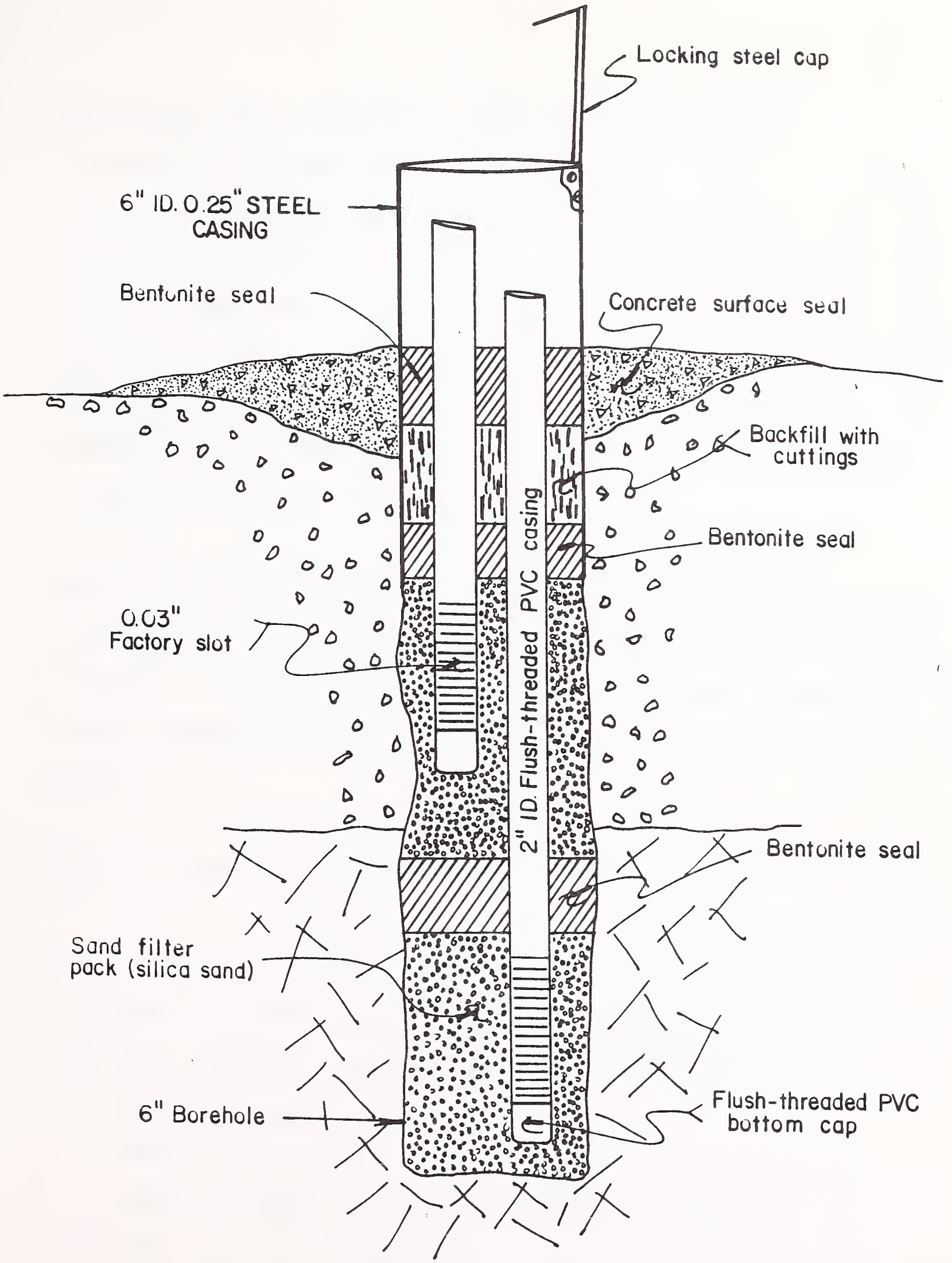


FIGURE 2-4

TYPICAL DUAL MONITORING WELL CONSTRUCTION

monitoring wells in December 1985 and January 1986. Attachment V presents static water level data collected during the RI. Static water levels were measured using electric well probes, and measurements were made to the nearest 0.1 foot from a designated measuring point on each well. The same set of well probes were used to measure all wells throughout the investigation. All well probes were calibrated periodically to a steel tape in accordance with the project Quality Assurance/Quality Control Plan (MultiTech and Stiller and Associates 1985).

Special efforts were made to obtain ground water-level measurements at domestic wells during times of minimal ground-water use by residents. Appropriate notations were made when measurements reflected suspected pumping water levels rather than static water levels.

2.2.5.3 Sample Collection

Both sub-surface material samples and ground-water samples were collected in the Warm Springs Ponds area during the RI. Material samples were collected concurrently with drilling activities at the following sites and depths:

- WSP-1 (2-4 ft., 6-8 ft.);
- WSP-2 (2-4 ft., 5-6 ft., 8-9 ft.);
- WSP-3 (2-4 ft., 5-6 ft.);
- WSP-4 (2-3 ft., 6-8 ft.).

Laboratory analytical results of the material samples are presented in Attachment VI. Physical descriptions of field samples are included in Attachment IV.

Parameters analyzed in the sub-surface materials are shown in Table 2-5. The analytical protocol for tailings and waste outlined in the RI Work Plan report was followed for the material samples. The texture as well as the chemical nature of each material was characterized. Chemical analyses included pH, specific conductance, and dissolved, exchangeable, and total concentrations for each of the key metals of concern: iron, maneganese, cadmium, copper, zinc, and lead. In addition, extractable molybdenum, arsenic, phosphorus, and total nitrate were analyzed. Total sulfur, sulfide, and sulfate also were measured.

Ground-water samples were collected at locations and frequencies described in Appendix B (the Ground Water and Tailings report). The sampling network consisted of 12 existing monitoring and domestic wells and five monitoring wells constructed during the Phase II ground-water study of this RI. Sampling methodologies were in accordance with those described in the RI Work Plan.

Prior to sampling ground water at monitoring wells, approximately three bore volumes of water were evacuated from each well using a PVC bailer. Final well evacuation was completed by using a bladder pump. Domestic wells were evacuated utilizing existing submersible

TABLE 2-5
PHASE II GROUND-WATER MATERIALS SAMPLING
ANALYTICAL PARAMETER LIST

Parameter	Method
pH	1:1 water, combination pH electrode
Specific Conductance (micromhos/cm)	paste, conductance bridge
Mechanical analysis	modified hydrometer (Sobek 1978)
Rock (> 2mm fraction %)	Gravimetric
Saturation Extract	Paste method, Richards 1954
saturation (%)	
Ca, Mg, Na, K (meq/l)	ICP
SAR	(Na/(Ca+Mg/2)·0.5
Cd, Cu, Fe, Mn, Pb, Zn (mg/kg)	ICP, graphite cell AA
1.0 N Ammonium Acetate Extract pH 5.5	Methods of Soil Analysis, #2
K	ICP
SO_4	turbidimetric
Cd, Cu, Fe, Mn, Pb, Zn (mg/kg)	ICP, graphite cell AA
Nitric Peroxide Digest (TOTAL)	USEPA, CLP procedure
Cd, Cu, Fe, Mn, Pb, Zn	ICP, graphite cell AA
NO_3-N	specific ion electrode
Arsenic	Olsen ($NaHCO_3$)
Arsenic	Halvorson (12 N HCl)
Phosphorus	Olsen ($NaHCO_3$)
Molybdeum	acidified ammonium oxalate
Total S	LECO analyser
Sulfide-S	serial HNO_3 digest, LECO

pumps. Indicator parameters (temperature, specific conductivity, and pH) were monitored for consistency during the evacuation process.

Water samples were collected from monitoring wells with a bladder pump connected to a decontaminated hoisting line. Sample water was obtained directly from the bladder pump and directed into the sample container. In existing domestic wells, samples were collected from a discharge line and on the well side of any water-conditioning device.

2.3 DATA ANALYSIS AND INTERPRETATION

The following section describes the methods of data analysis used in evaluating the RI data and historic data. The data base and its manipulation are briefly described; the methods specific to historic data analysis are recounted; and the methods most useful to analysis of current RI data are discussed. This section also reviews the metal removal mechanisms that may be important in the Warm Springs Ponds.

Data used in this analysis were entered into three main data bases, one for historic data and one each for surface-water and ground-water data collected during this RI. The data bases were established on a Data General MV4000 computer and on an IBM PC-AT. The historical and surface-water data bases were manipulated and statistical analyses were performed using the SAS® software (SAS Institute 1985). Because of the limited amount of ground-water data, statistical analyses were not appropriate for evaluation of these data.

Most analytical parameters were above their respective detection limits, although dissolved metals concentrations were often below the detection limit at both the Pond 3 and Pond 2 discharges.

A number of computer programs were developed to graphically display the data on a plotter. For each standard surface-water run, graphs were developed of flow at all stations measured and the loads of various parameters. Plots of concentrations of particular parameters at a single sampling station and over the sampling period also were developed. Additional graphs were developed to show the loads of various parameters at all stations on the Mill-Willow Bypass during the seepage runs.

These graphs demonstrate the spatial and temporal distributions of contamination, indicate sources of contamination, and suggest possible metal removal mechanisms.

2.3.1 Historic Data

Historic data collection methods were described in Section 2.1. Average loads were calculated for parameters such as zinc, copper, and iron, which also were analyzed in the RI. Samples in the historic data base generally were analyzed for metals using the State of Montana total recoverable method, whereas the RI water-quality samples were analyzed for dissolved and total metals. This difference makes comparison of metals data from the two data sets difficult.

Few samples within the historic data base were taken at more than one station on the same date, resulting in few loading graphs of the type developed for this RI.

2.3.2 RI Data

RI data were analyzed according to flow, parameter concentration, and parameter loadings. Flow was plotted for each run to show areas of streamflow increases or decreases. Known tributary inflows then were subtracted to identify reaches of possible groundwater inflow or stream loss.

Concentration plots for several parameters were made showing the variation in concentration between various inlets and outlets over the RI study period. These plots identify trends in data, which in turn lead to an understanding of some of the processes operating in the Warm Springs Ponds.

An important use of the data was to calculate loads of various parameters, allowing identification of contaminant sinks. Load is a measure of the amount of material that passes a given point in a given time. Load is calculated using the following equation, in the units of this report:

$$\text{Load (lbs/day)} = 5.3944 \times \text{Concentration (mg/L)} \times \text{Flow (cfs)}$$

The constant 5.3944 is a conversion factor that corrects for the change in units.

Loads calculated using data below the detection limit were set to zero to avoid interpretation errors. This procedure will result in a minimization of load releases by the ponds, and thus a maximization of calculated efficiencies. This approach results in the most conservative estimate of releases and greatest estimate of efficiencies. During the discussions in Chapter 3, these limitations should be considered: any release is a minimum release and may have been greater; and calculated efficiencies are maximums and may have been lower.

Loading analysis is particularly useful in interpreting the pond system operations, both removal mechanisms and contaminant removal efficiencies. Input loads could be added and compared with the loads measured at outputs to help identify removal processes and calculate efficiences. This analysis was performed for Pond 3, Pond 2, and the pond system as a whole.

Seepage run data on the Mill-Willow Bypass were analyzed for flow and load inputs other than measured tributary inflows. Loading calculations of various parameters were used to identify non-point sources of increased load to the bypass, such as ground-water inflow or bank entrainment.

Most of the data analysis centers around copper, iron, and zinc. These metals are not necessarily the most toxic to humans at the site, but they are selected for several reasons:

- Zinc and copper are of particular concern for aquatic life at the levels measured in Silver Bow Creek. Iron is important as an indicator of chemical conditions and often affects the behavior of other metals.

- These metals have the highest concentrations of all heavy metals in Silver Bow Creek and are generally above detection limits. They are also reliable, routine analyses.

- The historic data contain very few metal analyses other than zinc and copper. Analysis for these metals provide some comparability with historic data.

2.3.2.1 Data Validation

The QA/QC Plan prepared for the Silver Bow Creek RI (MultiTech and Stiller and Associates 1985) was closely followed. The QA/QC plan provides guidance in the following areas:

- Field procedures;
- Analytical laboratory protocol;
- Chain-of-custody procedures; and

- Data QA checks, including field measurement duplicates (flow, pH, SC, temperature); field blanks and duplicate samples; sample bank blanks, spikes, standards, and splits; laboratory blanks, spikes, calibration checks, and replicates; and referee laboratory duplicates.

Data generated during this RI were subjected to the rigorous Level B Data Reliability Criteria described previously in Section 2.1, and were considered validated if these criteria were met. The SBC RI Laboratory Quality Assurance/Quality Control Program (Appendix F) contains a more detailed QA/QC discussion.

Some data were not validated for a variety of reasons, such as excessive holding time or laboratory data QA checks. These data are marked with asterisks in the data listing and were not used in data analysis, except regarding the use of unvalidated TSS values. Some analytical batches did not include a standard sample, because such a standard was not available at that time and was not required by the QA plan. The TSS data were flagged for this reason alone and are probably valid by all other criteria.

Data generated by field duplicate samples were used to estimate total measurement error. Sampling error was calculated using this total error and laboratory error included with each laboratory report.

Propagation of error is also of concern. Consider, as an example, a load measurement which is a function of concentration and flow

(load = flow x concentration x unit constant). An average flow measurement might have a relative standard deviation (RSD) of 10% (0.1), and a water quality analysis, an RSD of 5% (0.05). The total RSD for the load is not simply an additive process of (0.1) plus (0.05) = (0.15), or 15%. To calculate the most probable RSD for the load, the following equation should be used:

$$R_L = \sqrt{(R_A)^2 + (R_F)^2}$$

Where:

R_F = Relative standard deviation (RSD) of the flow measurement

R_A = RSD of the water quality analysis

R_L = Most probable RSD of the load calculation.

The result of this example calculation shows the most probable RSD for the load to be .112, or 11.2%.

2.3.2.2 Mass Balance Study

Mass balance data were collected to determine the efficiency of the Warm Springs Ponds in trapping metals. Secondary objectives were the determination of sulfate and phosphate efficiencies and determination of pond seepage. Mass balance data were collected semi-monthly from June through the beginning of September 1985. The intervals for the mass balance calculation are therefore 15- or 16-day periods, with one sampling in each period.

The approach taken in determining the mass balance and pond efficiency was to treat the Warm Springs Ponds as a single system as outlined in Figure 2-5. This results in a mass balance and efficiency for the pond system as a whole. To separate the efficiencies of the two ponds, a second method calculated the mass balance and efficiencies of Pond 2 alone.

The data, programs, and output used in the mass balance calculation are included in Attachment VII, Mass Balance Data. The input data consist of water quality parameters, change in storage of the ponds, flow data, and evaporation and precipitation data. The order of parameters in the water quality input files is the same as the order in the output files. Programs are written in BASIC and run on an IBC PC or compatible computer.

Water Balance Model

The first step in calculating mass balance is to determine the water balance, including inflows, outflows, and changes in storage for the period. If a complete water balance is desired so that seepage can be determined, evaporation, evapotranspiration, and precipitation also must be calculated. These terms are not necessary to the actual constituent mass balance, because evaporation and precipitation do not add or remove significant constituent loads. The equation for the water balance model is (all measurements are in acre-feet):

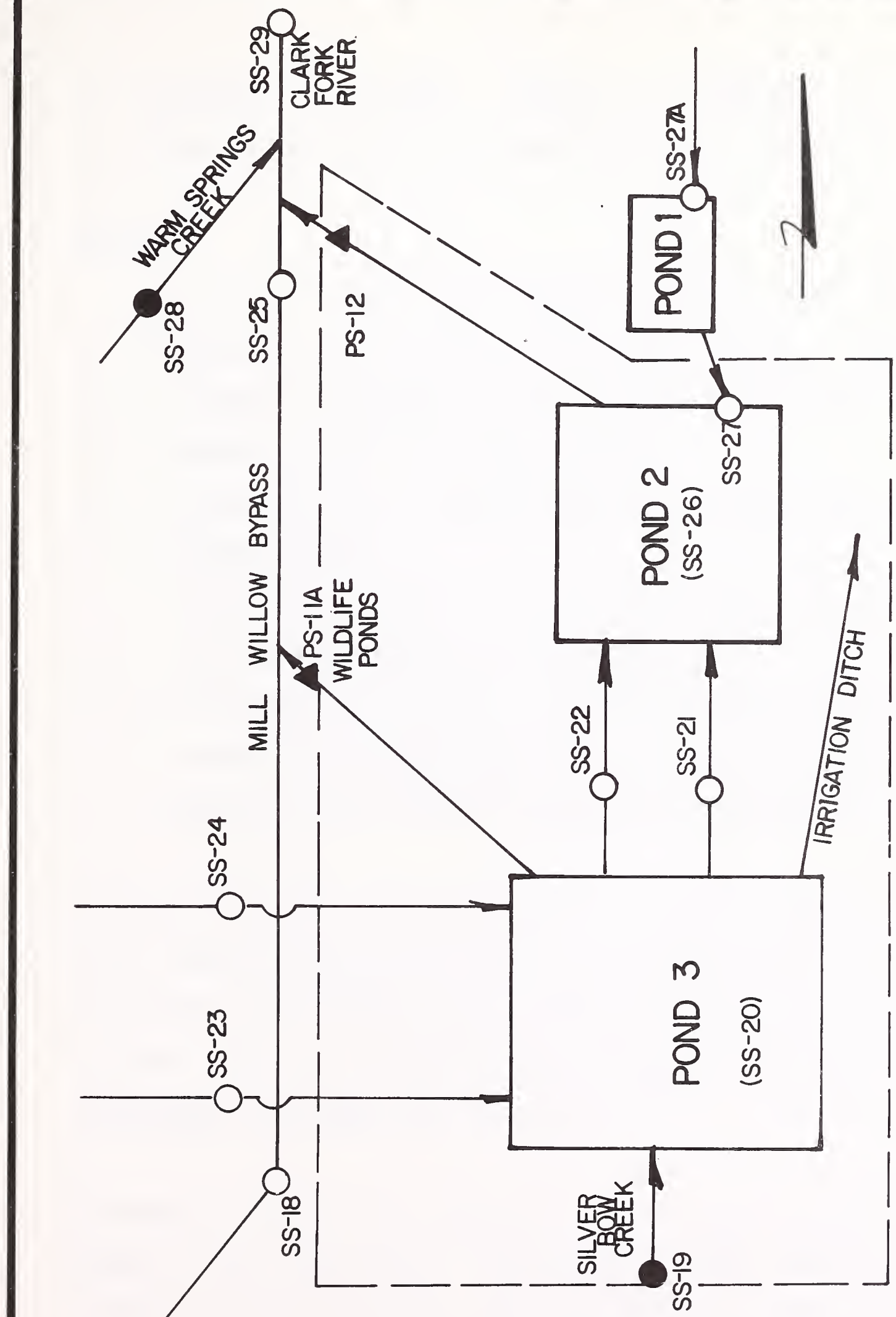


FIGURE 2-5
SCHEMATIC of the
WARM SPRINGS POND SYSTEM

Inflows - Outflows - Change in Storage - Evaporation - Evapotranspiration + Precipitation - Losses = 0

Where:

- Inflows are measured inflow volumes for the period;
- Outflows are measured outflow volumes for the period;
- Change in Storage is the increase in storage volume of both ponds during the study period;
- Evaporation is gross evaporation from both ponds for the study period;
- Evapotranspiration is the water loss through plants within the study area during the period;
- Precipitation is the water added by precipitation over the ponds and the watershed areas during the period;
- Loss is the unknown, unmeasured parameter in this equation.

Loss includes the combined total of pond bottom seepage, groundwater inflow (negative), change in soil moisture in the study area, runoff from surrounding area (negative), as well as all measurment errors. Loss is referred to as "seepage" in the output data in Attachment VII, Mass Balance Data.

Change in storage was computed on a daily basis from the staff gages in the two ponds. The elevation-area-capacity data used to compute storage volumes were developed from the bathymetric map produced by Cashell Engineers (1985) and the Anaconda Smelter Site map produced for that CERCLA site (Horizons, Inc. 1984). These

data are in Attachment VII, Mass Balance Data. The change in storage for a 15-day period is the difference between the ending storage volume and the beginning storage volume, and it can be either positive or negative.

Evaporation calculations included terms for Ponds 2 and 3 and the Wildlife Ponds. The areas of Ponds 2 and 3 are calculated on a daily basis from the AMC staff gage readings and the elevation-area-capacity tables. The Wildlife Ponds west of the west decant discharge from Pond 3 have a combined area of 52 acres. Evaporation and precipitation data for the ponds were gathered at approximately one-week intervals. These data are prorated over each collection period to give an average daily net evaporation and an average daily precipitation. Gross evaporation is calculated from the relation below:

Gross evaporation = Net evaporation + precipitation

Gross evaporation is reduced to gross pond evaporation using a pan coefficient of 0.7 (Chow 1964a). Gross pond evaporation and precipitation are converted to feet and multiplied by the approporiate pond areas to obtain quantities in acre-feet. Gross pond evaporation is subtracted from, and precipitation is added to, the water balance equation.

Evapotranspiration is calculated for an 80-acre marsh in the area east of the east Pond 3 discharge. The area is moisturized by

syphons from Pond 3, and 60 acres of grain fields east of Pond 2 are irrigated by another syphon from Pond 3. The grain fields were irrigated intermittently during June and continuously from June 25 to July 12, 1985, when irrigation ceased. This irrigated area is included in the transpiration calculation for the period early June to mid July.

Evapotranspiration is calculated from the following equation by Hargreaves (Chow 1964b):

$$U = k\ (E + 2.70)$$

Where:

- U is the monthly consumptive use of the plants;
- k is plant-dependent monthly consumptive use coefficient; and
- E is the monthly evaporation in inches.

The value of k is used for the 80-acre marsh is taken to be equal to that of alfalfa, a plant with high consumptive use, because no value is reported for the native vegetation. The value used varies from 0.64 to 0.74 depending on the month. The value of k for grain is 0.30 in June and 0.39 in July (Chow 1964b). Although these values are approximate, these evapotranspiration terms are not large enough to warrant further refinement.

Considerable evapotranspiration may also occur from the willows between the upper pH shack located above Pond 3, and Pond 3, as well as the marsh grasses between the two discharges from Pond 3.

These two areas comprise about 525 acres, but the rate of evapotranspiration is not known with any certainty because soil moisture conditions are not known. Although this area is not included in the calculations, some estimates of its magnitude are made to show its possible importance for the calculation of seepage.

Mass Balance Model

Using water balance data in conjunction with water quality data allows the calculation of the mass balance for sampled constituents in the RI study:

- Sulfate
- Total Iron
- Dissolved Iron
- Total Copper
- Dissolved Copper
- Total Zinc
- Dissolved Zinc
- Orthophosphate (as P)
- Total Phosphorous

The output sheets in Attachment VII, Mass Balance Data, show calculation for specific conductance as well. This parameter is multiplied by 0.67 to give an approximate indication of total dissolved solids, and it is useful for checking the operation of the mass balance programs.

The equation used to calculate the mass balance of a constituent is

Load in - Load out - Storage - Load loss = 0

Where:

- Load in is the load of a given constituent entering the system during the period.
- Load out is the load of a given constituent leaving the system during the period.
- Storage is the change in load of a given constituent stored in the pond water during the period.
- Load loss is the amount of constituent removed from the water.

The following equation calculates load:

Load (lbs) = 2.73 x Volume (acre-feet) x Concentration (mg/L)

The change in storage could be due to either a change in storage volume or a change in concentration in the ponds during the period. It can be either a positive or negative quantity. When it is negative, the ponds act as a source of material because the pond volume or the constituent concentration has decreased during the period.

Load loss is the material that is removed from the surface water system. Three pathways that may account for the lost material:

(1) Dissolved material is carried out of the pond bottoms with seepage water.

(2) Solid material is retained on the pond bottoms.

(3) Material changes chemically to another form. For example, dissolved metals may be adsorbed on suspended sediment or floating algae.

These three pathways cannot be distinguished using mass balance data alone.

Water quality data were not available for all parameters in every 15-day period. The Opportunity Pond discharges (SS-23 and SS-24), Pond 3 (SS-20), and Pond 2 (SS-26) were not sampled in early July, August, and September. Iron data for the Opportunity Pond discharges was not collected in late August. The Pond 1 pumpback was not sampled at these times either, nor was it operating during the late July and August samplings. Data for the Opportunity Pond discharges and the two ponds were interpolated for the missing periods, except for September when the concentrations were assumed to be the same as the late August sampling. Pond 1 pumpback data were not included in the mass balance calculations because the period of operation is uncertain and no water quality data were obtained after June; however, its potential effect was estimated.

Phosphate data were not collected for the Opportunity Pond discharges and in the two Warm Springs Ponds at any time. Because only inflow and outflow loads of phosphate were known, an accurate mass balance for phosphate was not possible. However, because of the magnitude

of the loss of total phosphorous, some general conclusions on phosphate removal can be made.

Calculation of Pond Efficiency

The definition of efficiency used in the Mass Balance Study is as follows:

$$\text{Efficiency in \%} = \frac{\text{Load loss}}{\text{Load in}} \times 100$$

Using the mass balance equation, this can be rewritten as:

$$\text{Efficiency in \%} = \frac{\text{(Load in-Load out-Storage)}}{\text{Load in}} \times 100$$

where Load in, Load out, and Storage are defined previously. If the change in storage is negative, the pond efficiency calculated from this formula can be greater tha 100%. This happens when the pond water acts as a source of material; for example, when the ponds decrease in volume. Such situations are temporary and would not be seen in long-term data.

Pond efficiencies are calculated for the pond system as a whole using the inflows, outflows, and change of storage presented earlier.

2.3.2.3 Pond System Operating Life

The purpose of the operating life study was to predict the useful life span of the Warm Springs Pond system. Data collected for this study include a bathymetric survey of Ponds 2 and 3 (Maps 2-1 and 2-2, both Over Size) to determine remaining pond volumes, water quality data from major inflows and outlets of the pond system (Attachment III), and chemical and density tests on pond bottom sediments (Attachment VIII).

Initially, mass balance calculations of Total Suspended Sediments (TSS) were used to estimate the sedimentation rate occurring in the ponds. However, these estimates proved inaccurate for several reasons:

- TSS cannot easily be converted to total sediment load.

- TSS is an insensitive analytical measurement with a large potential error (for example: algae growing in the ponds and measured at the outflow as TSS).

- Data for a large portion of the RI period (December through March) are lacking.

- 1985 was a low-water year and TSS and Total Sediment Load are very dependent on water volume and velocity.

- Sediment data collected are not sufficient to perform the required analysis.

An alternative method was devised using the USDA Soil Conservation Service (SCS) sediment yields for the Silver Bow Creek and the upper Clark Fork River Basin (USDA-SCS, 1977). The area of the Silver Bow Creek drainage system above the Warm Springs Ponds was measured using a planimeter, and the areas not draining into Silver Bow Creek were subtracted. Multiplying the sediment yield by the total drainage area gives the average volume of sediment carried by Silver Bow Creek per year. Taken together with bathymetric survey data (Cashell Engineers 1985), this information then was used to estimate the remaining life of the ponds. This approach, while a gross estimate, provides an order of magnitude prediction and is the best possible using the limited existing data.

2.3.3 Hydrogeochemical Hypotheses

The transport and fate of metal contaminants in the Warm Springs Ponds area are controlled by several interrelated hydrogeochemical mechanisms. Though each mechanism is a distinct chemical phenomenon, the data collected during this study are insufficient to conduct a detailed investigation into the variety of possible chemical processes acting in this system. However, three potentially important mechanisms can be semi-quantified from the existing RI data and used to evaluate metals behavior in the Warm Springs Ponds:

- Dissolution and precipitation of metal compounds;
- Adsorption and desorption of metal ions; and
- Physical aggregation and settling of particulates.

The possible role of algae in the accumulation and transport of metals is discussed in the Algae Investigation Report, Appendix D, Part 1.

The chemical forms of a particular metal can be very important for assessing potential toxicity. The Bioassay Investigation (Appendix E, Part 2) evaluates the actual toxicity of metals on young fish populations in the upper Clark Fork River. The various metal species present theoretically can be calculated from measured concentrations, but this usually represents an approximation and can be misleading. Figure 2-6 summarizes the more common forms of metals found in natural waters and some of their interactions with one another.

2.3.3.1 Dissolution and Precipitation of Metal Compounds

Predicting the dissolution and precipitation of various metal compounds rests on the basic assumption that thermodynamic equilibrium is approached or attained by the system being studied. Several factors control calculated thermodynamic stabilities, including pH, oxidation potential, temperature, ligand concentrations, and activity coefficients.

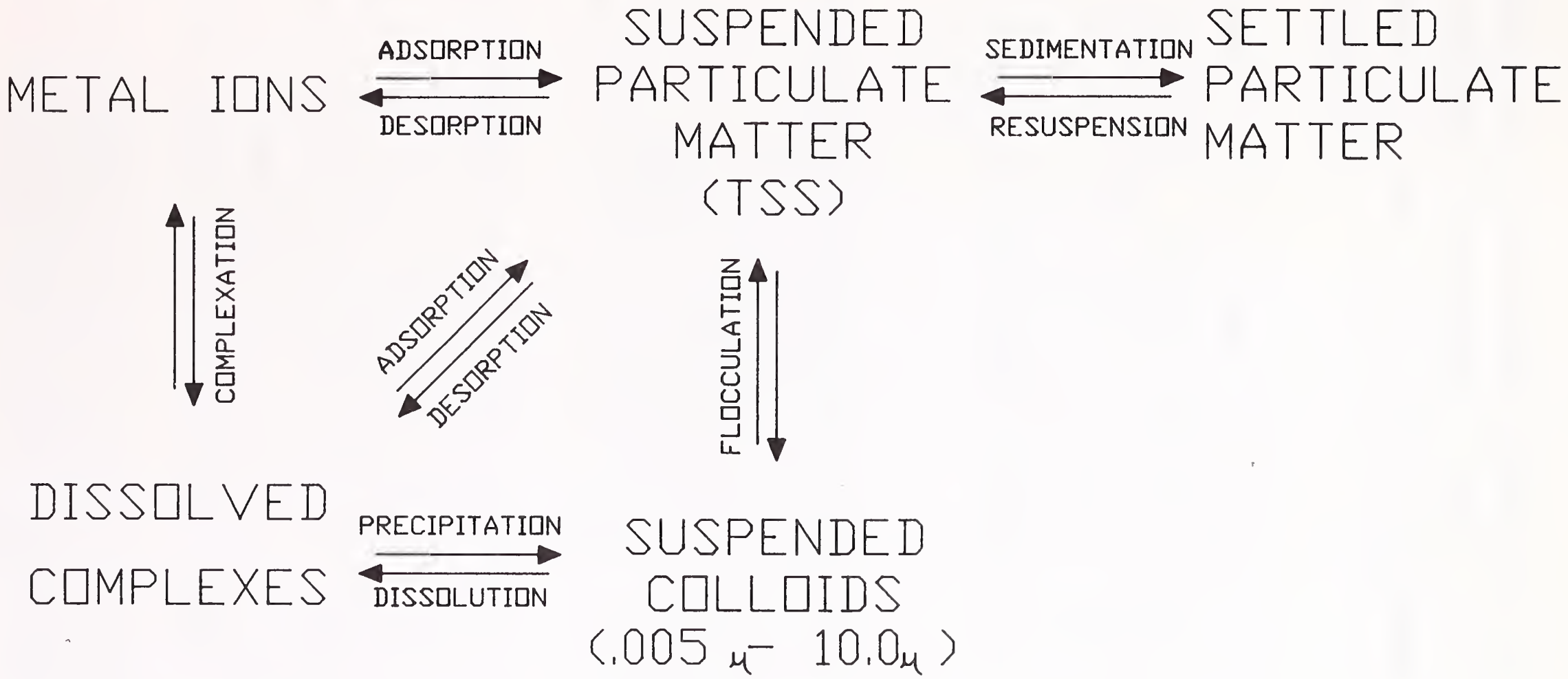


FIGURE 2-6 COMMON FORMS OF METALS
IN NATURAL WATERS
(after Salomons & Forstner, 1984)
p.14

Hydrogen ion concentrations (measured as pH) are an important factor in stability relationships. During the study period, pH in the ponds varied from 6.5 to 10.0, a considerable range for equilibrium calculations.

Oxidation potential data, measured as Eh in volts, was not collected in this study. However, Eh for a large surface-water body like the Warm Springs Ponds is usually moderately oxidizing, ranging from 0.3 to 0.5 volts (Hem 1970). This range is not generally sufficient to cause changes in stabilities of most of the compounds of interest.

Temperature was measured during the study and ranged from 0 to 25°C, though the range during any given sampling episode was only a few degrees. The small temperature differences and the relatively small effect of temperature on mineral stabilities make the effects of temperature relatively insignificant for equilibrium calculations.

The concentration of various ligands in solution with metals is very important to the calculation of relative stabilities. Ligands such as carbonate, sulfate, and hydroxide were all measured, while organic complexing ligands were not. These measurements are important in determining the affinity of the various complexing agents to form stable complexes and precipitates.

Activity coefficients are important in relating measured concentrations of a constituent to those effectively available for chemical

reaction (activity). The activity of a particular species is very dependent on the ionic strength of the solution, which indicates the effect of competing species also available for reaction. Ionic strengths in the Warm Springs Ponds were calculated using data generated during the seepage runs, which included measurements of major cations and anions in addition to the routine analyses. These calculations indicate that the activities for many of the species of interest are significantly reduced by the high concentrations of dissolved solids in the ponds. Solubility diagrams have been prepared for copper, zinc, and iron (Figures 2-7, 2-8, and 2-9, respectively) using averages of the important parameters discussed above that were measured in the Warm Springs Ponds during the RI.

A variety of problems can arise from assuming equilibrium. Thermodynamics serves to predict the direction and extent of chemical change in a system. The rate at which these changes occur (kinetics) is very important to the observed chemical composition. Reaction kinetics for most of the species of interest in this study have not been well documented. Both the iron and manganese systems have been studied, however, and rate equations have been derived for several reactions (Stumm and Morgan 1981). The following is an example of the effects of reaction kinetics:

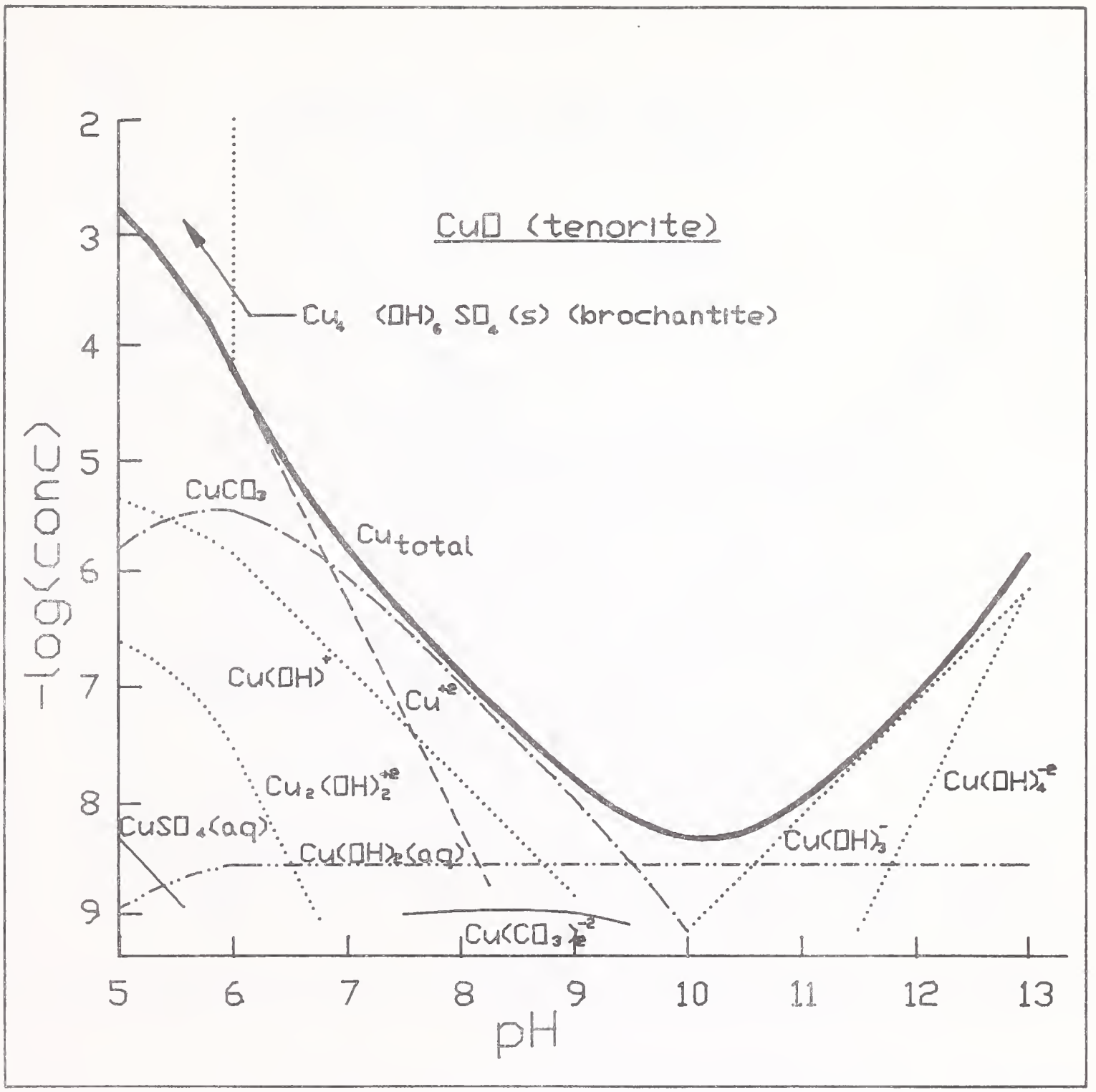


FIGURE 2-7
SOLUBILITY OF COPPER

Equilibrium constants were adjusted to ionic strength of 0.0065, and calculations assumed total carbonate (carbonic acid, bicarbonate, and carbonate) was fixed at 100 mg/L as $CaCO_3$ and sulfate at 110 mg/L, conditions representative of the Warm Springs Ponds. Data was not available to correct equilibrium constants from 25°C to conditions representative of Silver Bow Creek. The maximum error due to temperature variation from 25°C was estimated to be 0.2 log units in total copper concentration. Species considered were CuO (tenorite), $Cu_2(OH)_2CO_3$ (malachite), $Cu_3(OH)_2(CO_3)_2$ (azurite), $CuCO_3(aq)$, Cu^{2+}, $CuOH^+$, $Cu(OH)_2$ (aq), $Cu(OH_3)^-$, $Cu(OH)_4^{2-}$, $H_2CO_3^-$, CO_3^{2-}, $Cu_2(OH)_2^{2+}$, OH^-, and H^+. Equilibrium constants are from Stumm and Morgan (1981), except the formation constants for $CuOH^+$ and $Cu(OH)_2$ (aq) are from Morel (1983).

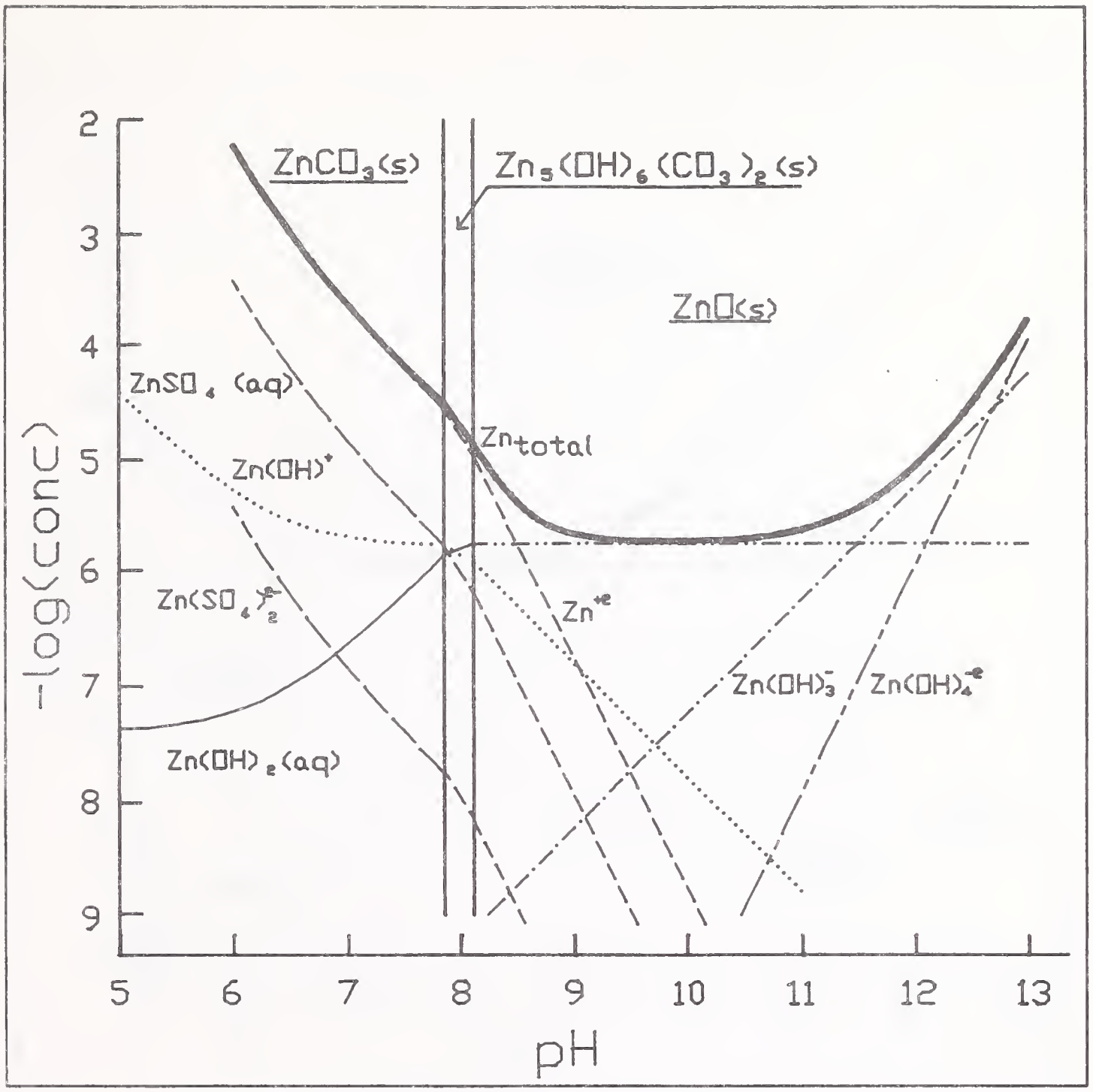


FIGURE 2-8
SOLUBILITY OF ZINC

Equilibrium constants were adjusted to ionic strength of 0.0065, and calculations assumed total carbonate (carbonic acid, bicarbonate, and carbonate) was fixed at 100 mg/l as $CaCO_3$ and sulfate at 110 mg/L, conditions representative of the Warm Springs Ponds. Data was not available to correct equilibrium constants from 25°C to conditions representative of Silver Bow Creek. The maximum error due to temperature variation from 25°C was estimated to be 0.2 log units in total zinc concentration. Species considered were $ZnO(s)$, $Zn(OH)_2$ (amorphous), Zn^{2+}, $ZnOH^+$, $Zn(OH)_2$ (aq), $Zn(OH)_3^-$, $Zn(OH)_4^{2-}$, $ZnCO_3(s)$, $Zn_5(OH)_6(CO_3)_2$ (hydrozincite), $ZnSO_4(aq)$, $Zn(SO_4)_2^{2-}$, $H_2CO_3(aq)$, HCO_3^-, CO_3^{-2}, OH^{-2}, and H^+. Equilibrium constants were taken from Stumm and Morgan (1981).

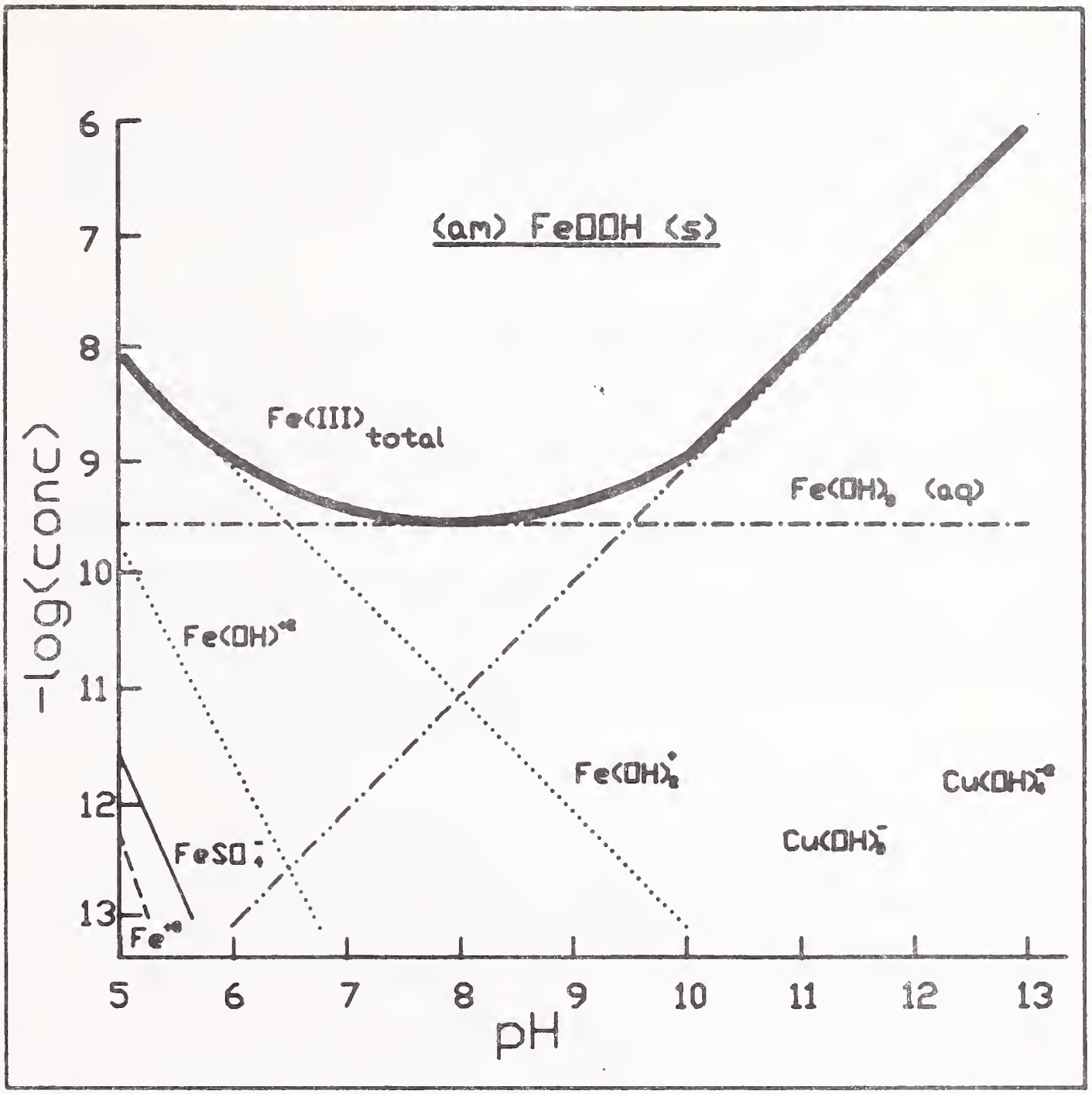


FIGURE 2-9
SOLUBILITY OF Fe (III) SPECIES

Equilibrium constants were adjusted to ionic strength of 0.0065, and calculations assumed total carbonate (carbonic acid, bicarbonate, and carbonate) was fixed at 100 mg/L as $CaCO_3$ and sulfate at 110 mg/L, conditions representative of the Warm Springs Ponds. Data was not available to correct equilibrium constants from 25°C to conditions representative of Silver Bow Creek. The maximum error due to temperature variation from 25°C was estimated to be 0.2 log units in total Fe (III) concentration. Species considered were FeOOH (amorphous), $FeOH^{2+}$, $FeOH_2^+$, $Fe(OH)_3$ (aq), $Fe(OH)_4^-$, $Fe_2(OH)_2^{4+}$, $FeSO_4^-$, H_2CO_3, HCO_3^-, CO_3^{2-}, OH^-, and H^+. Equilibrium constants were taken from Stumm and Morgan (1981).

Using the thermodynamic equilibrium model for the iron system (Figure 2-6), a pH change from 6.0 to 7.0 should cause dissolved Fe^{2+} to form the precipitate $Fe(OH)_3$. However, before that can happen, Fe^{2+} must be oxidized to Fe^{3+}, which is a relatively slow process that is also pH- dependent (at pH=4, 10 years to completion; at pH = 7.5, 1.1 hours to completion).

Reaction kinetics, rather than thermodynamics, may dictate which metal species predominate in the waters of the Warm Springs Ponds. Supersaturation of the water with respect to a given constituent can occur easily and would yield dissolved concentrations higher than that calculated thermodynamically. Possible constraints due to reaction kinetics must be carefully considered when using thermodynamic solubility information.

A variety of organic substances can form complexes with metals that will alter the dissolved metal concentrations from those expected. Without a direct measurement of these organic complexes, their effect on dissolution and precipitation of metals is difficult to interpret. These organic compounds have a significant influence on metals in most surface-water systems.

Algae may indirectly influence metals behavior in the ponds. During periods of photosynthetic activity, algae assimilate carbon dioxide out of solution, thereby increasing the pH. This activity may change the pH enough to cause the precipitation of some metals out of solution (Fogg 1965). Other aquatic organisms can affect the chemical speciation of certain metals and thereby complicate the interpretation of data.

2.3.3.2 Adsorption and Desorption of Metal Ions

Adsorption is a major process governing the transport and fate of metals in the Warm Springs Ponds, perhaps more important than precipitation. There are three categories of adsorption phenomena:

- Physical adsorption of solutes on the external surfaces of particles due to the relatively weak Van der Waals forces between them;

- Chemical associations between ions in solution and those on the surface of particles; and

- Ion exchanges involving positive or negative surface charges, attracting oppositely charged ions from the solution.

The surfaces required for adsorption can be provided by precipitated iron and manganese oxides and hydroxides, organic matter, and silt or clay particles. After initial adsorption on a surface (especially iron hydroxides), metal ions may become overgrown by the precipitating phase and be removed from the system. This process is also known as coprecipitation or occlusion. Several factors can control the amount of metals affected by adsorption, including the following:

- The activity of the metal in the solution (calculated from the ionic strength);

- The pH of the solution--generally higher pH leads to increased metal adsorption (Figure 2-10) and decreased arsenic adsorption;

- The number or density of adsorption sites (or total surface area available), which can be roughly correlated with TSS concentration;

- The activity of competing adsorbate ions in the solution;

- The concentration of ligands available to complex or precipitate metals and the thermodynamic stability and reaction kinetics of those species; and

- The kinetics of adsorption processes, which can have equilibration times of minutes to hours (Morel 1983).

Interactions between particles and metal species play an important role in the regulation of dissolved metal concentrations. Adsorption can be the first step in the ultimate removal of trace metals from the aquatic environment. Not enough data were collected to provide more than a qualitative estimate of specific adsorption/desorption phenomena in the Warm Springs Ponds system.

2.3.3.3 Physical Aggregation and Settling of Particulates

This mechanism is very important in the removal of contaminants by the Warm Springs Pond system. It includes the removal of several forms

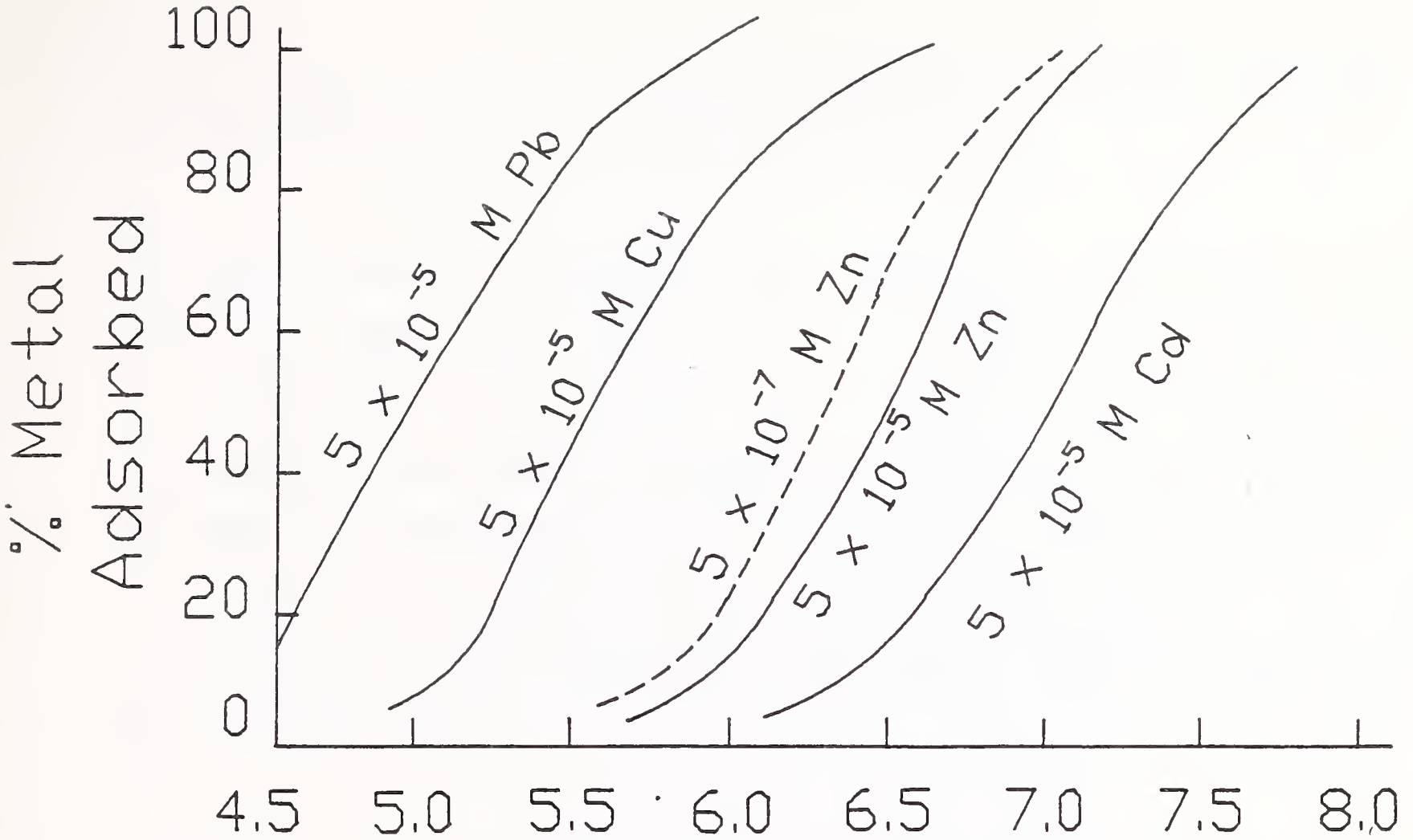


FIGURE 2-10

Fractional adsorption of metals on amorphous $Fe(OH)_3$ substrate (1×10^3M Fe (OH_3) demostrating the effects of pH, metal concentration (Zn), and different metals on adsorption tendencies (Salomons and Forstner 1984).

of particulate material: metal precipitates, metals adsorbed to particle surfaces, and metalliferous sediments.

Two physico-chemical processes are operating on particles in this mechanism: aggregation and settling. Aggregation of very small (e.g. colloidal) particles to form larger, denser particles by collision and coagulation, is dependent on the size of the coagulating particles, the temperature and turbulence of the water, and residence time. Settling of aggregated particles and sediment is a function of the particle size and density, the energy regime of the water, and residence time.

As water enters the ponds from Silver Bow Creek, it encounters a much lower energy environment. Water velocities are reduced considerably, decreasing the ability of the water to move and suspend sediment. Additionally, the long residence time (estimated to be 2-3 days) and the addition of lime enhance the aggregation and settling of particulate material entering the Warm Springs Ponds.

2.3.3.4 Analytical Constraints

Water samples collected during the Silver Bow Creek RI were routinely analyzed for metals in two ways. One split of the sample was filtered through a 0.45 micron (μ) filter before analysis to segregate "dissolved" metal species: free metal ions, inorganic ion pairs, and soluble inorganic and organic complexes. Another unfiltered split was analyzed for "total" metals. This measure

included all the dissolved metal species listed above, plus those metals associated with suspended particulates: metals adsorbed on particle surfaces, precipitated metal compounds, and metals bound within the mineral matrix.

Adsorbed metals' concentrations were determined using an "extractable metals" procedure, but this was done on only two sampling episodes. Subtracting "dissolved" metals from "extractable" metals yields a good approximation of metals present as adsorbed species. Subtracting both the "dissolved" and "extractable" metals from the "total" metals yields the metal that is bound within the mineral matrix of the sediment. Although a filter was used to separate dissolved metals from suspended metals, some colloidal particles (0.005μ to 10.0μ diameter) could pass through the 0.45μ filter. Some metals tend to form colloidal oxide or hydroxide precipitates; for example, iron forms ferric hydroxide ($Fe(OH)_3$). Metal concentrations measured in the filtered split may actually include some colloidal material, and this material could cause equilibrium calculations to be inaccurate. The extent of this problem is unknown. Though it has limitations, filtration is still the best available technique for separating dissolved constituents.

These analytical extraction techniques limit predictions of theoretical chemical speciations and interactions. However, useful insight into the major chemical and physical processes as they apply to contaminant transport mechanisms and fate can be derived from these measurements.

DRAFT

3.0 DATA ANALYSIS AND INTERPRETATION

Historic and RI-generated data from the Warm Springs Ponds area were reviewed, analyzed, and interpreted for this report. Emphasis was placed on the RI data for interpretations, and historic data was used mainly for comparison. This chapter is organized into three sections which reflect the systems operating in the WSP study area: the Warm Springs Ponds system, the Mill-Willow Bypass, and the ground-water system. A comprehensive evaluation of the entire Warm Springs Ponds area is in Chapter 4.0.

The RI data used in this report is included as Attachment III. Prior to any discussion, the quality of the RI data must be examined. Quality Assurance/Quality Control (QA/QC) data generated by the laboratory for both laboratory and field duplicates were included with each lab report and are compiled, averaged, and presented in Table 3-1. Absolute values of percent deviation were used in calculating the average percent deviation. Precision is important when comparing data points within any one study; accuracy is important when comparing data from different studies. Since only RI-generated data were used in this evaluation, precision is most important and is presented in the table. These data were used to determine the resultant precision of loading calculations. QA/QC procedures show the RI data to be very precise (reproducible), and the resulting load calculations to be very precise also. With this data quality information, RI data can be interpreted within a known

TABLE 3-1
SBC RI SURFACE WATER DATA QA/QC SUMMARY

Parameter Measured[a]	Average Lab Precision (R_A)	Average Field Duplicate Precision (R_D)	Average Precision of Load Calculations (R_L)[b]
	+%	+%	+%
Sulfate	1.9	2.7	3.5
Cu (D)	2.8	5.5	5.9
(T)	3.1	6.9	7.2
Zn (D)	1.7	5.5	5.9
(T)	2.4	3.5	4.1
Fe (D)	2.4	7.1	7.4
(T)	2.8	6.9	7.2
As	4.7	8.2	8.5
Pb	4.4	8.2	8.5
Cd	4.9	6.3	6.7
pH	--	0.7	--
Flow (R_F)	--	2.2	--

Notes:

(a) D = dissolved, T=total

(b) $R_L = \sqrt{(R_F)^2 + (R_D)^2}$

confidence interval. Differences less than that confidence interval were ignored unless the observation was consistent.

The data collected for this RI represented conditions during the period December 1984 through August 1985. This period was drier than average, which may have affected pond operating conditions. Although precipitation for 1985 was below average, it was a typical year. Years that are as dry as 1985 are well within one standard deviation of the average. This means drier years, like 1985, are quite common in the area (see the Surface Water and Point Source report, Appendix A, for further discussion).

Additionally, the RI data represent a unique set of data, in that the Weed Concentrator was not discharging to Silver Bow Creek. The data collected during the RI therefore represent the lasting effects of past mining activities in the Summit Valley.

3.1 WARM SPRINGS TREATMENT POND SYSTEM

3.1.1 Historic Data

Three significant operational changes since 1975 have affected the quantity and quality of water entering the Warm Springs Ponds. First, on-site treatment of the Weed Concentrator discharge, initiated in 1975, measurably decreased metal loads discharged to Silver Bow Creek. The closure of the Anaconda Smelter in 1980 greatly reduced the quantity and improved the quality of water discharging

from the Opportunity Ponds (SS-23 and SS-24) to the pond system. The third change was the suspension of mining activities at Butte during 1983, which terminated all discharges from that source. This historic data analysis does not attempt to address the period before 1975.

3.1.1.1 Inflows

Silver Bow Creek is the primary inflow to the Warm Springs Ponds. Based on analysis of instantaneous discharge data, Silver Bow Creek had an average discharge of 63 cfs during the period 1975 to 1983 (Table 3-2, SS-17 for the years 1975-79, SS-19 for 1983). This compares to the average flow measured at SS-19 of 66 cfs (range of 28-112) during the RI period.

Average inflow, outflow, and concentrations for arsenic, cadmium, copper, iron, lead, and zinc, for the 1975-1983 time period are shown in Tables 3-3 through 3-6. During the period from 1975 to 1980, water quality data for Silver Bow Creek show that the primary drinking water standard for cadmium was exceeded approximately 25% of the time; and for lead, less than 10% of the time. The standard for arsenic was seldom exceeded.

Nutrient loads entering the pond system historically have been fairly high, with orthophosphate and total phosphorus averaging 0.16 and 0.63 mg/L, respectively. Nitrate and Kjeldahl nitrogen concentrations averaged 1.9 and 1.7 mg/L, respectively.

TABLE 3-2
FLOW AND AVERAGE CONCENTRATIONS (mg/L) FROM 1975 TO 1983[a,b]

	RI Sample Station				
Parameter	SS-17[c]	SS-23	SS-24	SS-25	PS-12
Flow (cfs)	63	22	4	39	108
Total Cu	0.436	0.092	0.260	0.047	0.056
Diss Cu	0.072	0.044	0.114	0.024	0.035
Total Fe	1.93	0.472	1.11	0.48	0.276
Diss Fe	0.073	0.065	0.082	0.070	0.048
Total Zn	1.22	0.095	0.423	0.135	0.127
Diss Zn	0.562	0.063	0.376	0.100	0.093
Total Pb	0.026	0.006	0.004	0.006	0.004
Total As	0.012	0.049	0.064	0.014	0.013
Total Cd	0.008	0.002	0.010	0.003	0.003
Sulfate	454	440	1175	295	443

Notes:

(a) Source: Anaconda Minerals Company files.
Measurement less than detection set to zero.
(b) Number of samples per mean can be calculated from data presented in Tables 3-3 through 3-6.
(c) Measurements were taken at SS-19 in 1983 and during the RI.

TABLE 3-3
SILVER BOW CREEK INFLOW TO THE WARM SPRINGS PONDS 1975-1983(a,b)

	1975		1976		1977		1978		1979		1983		RI(c)	
	$\bar{X}$	N	$\bar{X}$	N	$\bar{X}$	N	$\bar{X}$	N	$\bar{X}$	N	$\bar{X}$	N	$\bar{X}$	N
FLOW	68cfs	18	76	12	59	29	82	8	42	16	96	9	66	12
Total As	<0.002	15	0.010	12	0.009	20	0.001	8	0.008	16			0.019	12
Diss As														
TR As														
Total Cd	0.009	15	0.006	12	0.007	20	0.009	8	0.005	16	<DL	2	0.001	12
Diss Cd														
TR Cd					0.009	9								
Total Cu	0.46	15	0.369	12	0.372	20	0.826	8	0.342	16			0.170	12
Diss Cu			0.065	12	0.073	20	0.101	8	0.06	16			0.048	12
TR Cu					0.602	9					0.457	10		
Total Fe	2.34	15	1.60	12	1.98	20	2.62	8	1.37	16			0.979	12
Diss Fe			0.05		0.087	20	0.046	8	0.09	16			0.045	12
TR Fe											0.866	8		
Total Pb	0.025	15	0.007	12	0.032	20	0.062	7	0.01	16			0.011	12
Diss Pb			<0.001	12	<0.0008	20	<0.0005	8	0.0005	16				
TR Pb														
Total Zn	1.27	15	1.088	12	1.31	20	1.76	8	0.911	16			0.415	12
Diss Zn			0.48	12	0.620	20	0.806	8	0.453	16			0.163	12
TR Zn											0.609	10		

(a) All metals in mg/L. Measurements less than detection set to zero.
(b) SS-17, 1975-1979; SS-19, 1983.
(c) SS-19 December 1984 - August 1985; duplicates included.

TABLE 3-4
OPPORTUNITY POND DISCHARGE TO THE WARM SPRINGS PONDS: SS-23, 1975-1983[a]

	1975		1977		1978		1979		1980		1983		RI[b]	
	$\bar{X}$	N	$\bar{X}$	N	$\bar{X}$	N	$\bar{X}$	N	$\bar{X}$	N	$\bar{X}$	N	$\bar{X}$	N
FLOW	39.4	1	18	8	23	40	16	27	30	30	3.4	1	1.31	16
Total As	<0.01	1	0.088	10	0.10	49	<0.005	34	<0.0009	42			<DL	15
Diss As														
Total Cd	0.004	1	0.002	12	0.002	49	0.001	34	<0.0004	42			<DL	16
Diss Cd														
Total Cu	0.06	1	0.049	12	0.118	49	0.061	34	0.103	42	0.02	1	0.028	16
Diss Cu			0.029	12	0.040	49	0.04	34	0.051	42	<0.01	1	0.006	16
Total Fe			0.538	12	0.465	49	0.428	34	0.503	42			8.04	15
Diss Fe			0.041	12	0.418	48	0.082	34	0.087	42			5.72	15
Total Pb	0.01	1	0.025	12	0.006	49	0.002	34	<0.0006	42			0.010	15
Diss Pb			0.014	12	0.0004	48	0.0001	34	<0.002	42				
Total Zn	0.04	1	0.043	12	0.102	49	0.071	34	0.115	42	0.450	1	0.308	16
Diss Zn			0.017	12	0.066	48	0.035	34	0.086	42	0.380	1	0.294	16

(a) All metals in mg/L. Measurements less than detection set to zero.
(b) December 1984 - August 1985, duplicates included.

TABLE 3-5
OPPORTUNITY POND DISCHARGE TO THE WARM SPRINGS PONDS: SS-24, 1975-1983[a]

	1975		1977		1978		1979		1980		1983		RI[b]	
	$\bar{X}$	N	$\bar{X}$	N	$\bar{X}$	N	$\bar{X}$	N	$\bar{X}$	N	$\bar{X}$	N	$\bar{X}$	N
FLOW	7	1			5	13	4	24	4	28	3.3	1	0.97	15
Total As	0.01	1	0.031	5	0.115	49	0.021	34	0.031	30			0.004	14
Diss As														
Total Cd	0.008	1	0.043	5	0.010	49	0.006	34	0.008	80			0.001	14
Diss Cd														
Total Cu	0.10	1	0.316	5	0.220	49	0.096	34	0.513	30	0.02	1	0.032	15
Diss Cu			0.134	4	0.088	48	0.048	34	0.228	30	<0.01	1	0.001	15
TR Cu													<DL	2
Total Fe	0.36	1	0.952	5	1.09	49	0.967	34	1.36	30			0.586	13
Diss Fe			0.064	4	0.08	48	0.113	34	0.05	30			0.377	14
Total Pb	0.03	1	0.019	5	0.002	49	0.001	34	0.002	30			0.015	14
Diss Pb			0.0007	4	<DL	48	0.0007	34	0.0008	30				
Total Zn	0.09	1	0.876	5	0.410	49	0.278	34	0.561	30	0.06	1	0.209	14
Diss Zn			0.934	4	0.332	48	0.244	33	0.529	30	0.05	1	0.054	15
TR Zn													0.050	2

(a)All metals in mg/L. Measurements less than detection set to zero.
(b)December 1984 - August 1985, duplicates included.

TABLE 3-6
WARM SPRINGS PONDS DISCHARGE: PS-12, 1975-1983[a]

	1975		1976		1977		1978		1979		1980		1981		1983		RI[b]	
	$\bar{X}$	N	$\bar{X}$	N	$\bar{X}$	N	$\bar{X}$	N	$\bar{X}$	N	$\bar{X}$	N	$\bar{X}$	N	$\bar{X}$	N	$\bar{X}$	N
FLOW	160	43	138	52	76	55	101	53	82	50	113	41	102	46	96	13	45	24
Total As	0.03	44	0.002	52	0.014	46	0.009	53	<0.002	50	<0.005	41	<0.004	47			0.012	21
Diss As																	0.009	1
TR As																		
Total Cd	0.005	43	0.005	52	0.005	46	0.0009	53	0.001	50	0.002	41	0.002	46	<0.004	7	<0.001	21
Diss Cd															<0.005	1	0.002	1
TR Cd					0.002	9									<0.005	12		
Total Cu	0.083	43	0.048	52	0.044	46	0.048	53	0.055	50	0.064	41	0.058	46	0.068	8	0.047	21
Diss Cu			0.034	46	0.032	45	0.034	53	0.036	50	0.040	44	0.033	44	0.020	2	0.009	21
TR Cu					0.032	9									0.026	12	<DL	5
Total Fe	0.279	42	0.182	52	0.219	46	0.263	53	0.289	50	0.340	41	0.388	46			0.396	21
Diss Fe			0.040	46	0.044	45	0.034	53	0.078	50	0.043	41	0.043	47			0.023	21
TR Fe																		
Total Pb	0.016	42	0.003	52	<0.001	46	0.0003	53	0.001	50	0.0007	41	0.0007	47			0.003	21
Diss Pb			<DL	46	<0.001	45	<0.0008	53	0.0002	50	<0.0001	41	<0.0004	47			0.117	1
TR Pb																		
Total Zn	0.125	41	0.083	52	0.087	46	0.113	53	0.150	50	0.197	41	0.153	47	0.101	8	0.133	21
Diss Zn			0.056	46	0.064	45	0.091	53	0.117	50	0.145	41	0.093	47	0.020	2	0.084	21
TR Zn					0.016	9									0.093	12	0.043	5

(a) All metals in mg/L. Measurements less than detection set to zero.
(b) December 1984 - August 1985, duplicates included.

The two Opportunity Ponds discharges to the Warm Springs Ponds system (SS-23 and SS-24, Map 1-2 Over Size) had average flows during the period 1975 to 1982 of 22 and 4 cfs, respectively (Table 3-2). Comparing these values to the average flow at station SS-17 on Silver Bow Creek near Opportunity shows that during this time period, the combined flow from stations SS-23 and SS-24 accounted for approximately 30% of the inflow to the Warm Springs Ponds system. During the RI period, SS-23 averaged 1.31 cfs (n = 16, range 0.15 to 2.3 cfs) and SS-24 averaged 0.97 cfs (n = 15, range 0.36 to 1.8 cfs).

Station SS-24 exhibited significantly higher concentrations of total copper, iron, zinc, cadmium, and sulfate than did SS-23 for the 1975-1983 period. Metals concentrations in both of these discharges were generally less than those at station SS-17 during this time frame, the only exception being arsenic. Sulfate at SS-23 was about the same as at station SS-17, while the sulfate at SS-24 was more than double that at station SS-17.

Primary drinking water standards were exceeded at SS-23 for arsenic about 15% of the time and also occasionally for cadmium during the period from 1975 to 1980. Cadmium concentrations at SS-24 exceeded primary drinking water standards during approximately 30% of the sampling episodes; arsenic was above the primary drinking water standard about 4% of the time.

3.1.1.2 Discharges

The Pond 2 discharge (PS-12, Map 1-2 Over Size) had an average discharge of 108 cfs during the period from 1975 to 1983 (Table 3-2). The reason that this is greater than the average combined inflows described previously is that measurement dates and the number of measurements are different. Sulfate concentrations at PS-12 are very similar to sulfate concentrations of inputs from Silver Bow Creek to the Warm Springs Ponds, while all measured metals average concentrations decreased. The most notable decreases were total copper and zinc. Decreased concentrations in the other metals were also observed, but were not as great as for copper and zinc.

The historic data also indicate that the average concentration of nutrients in the Pond 2 discharge (PS-12) was typically very low, with orthophosphate and total phosphorus concentrations of 0.005 and 0.028 mg/L, respectively. Average nitrate and Kjeldahl nitrogen concentrations were 0.21 and 0.46 mg/L, respectively.

3.1.1.3 Loads

Table 3-7 presents loads released to the Clark Fork and pond efficiency data for historical data (1978-1980). Values in this table were calculated to facilitate comparison with RI data. Sixteen observations from the historical data base had measurements of flow, total arsenic, total cadmium, total copper, total iron, total

TABLE 3-7
WARM SPRINGS PONDS EFFICIENCIES: 1978-1980(a,b)

DATE(c)	Total As		Total Cd		Total Cu		Total Fe		Total Pb		Total Zn	
	lbs/day entering CFR	% Load left in ponds	lbs/day entering CFR	% Load left in ponds	lbs/day entering CFR	% Load left in ponds	lbs/day entering CFR	% Load left in ponds	lbs/day entering CFR	% Load left in ponds	lbs/day entering CFR	% Load left in ponds
78-09-19	0	100	0.56	66	34.0	92	141	93	0.57	98	5.6	99
78-09-26			0.56	84	22.3	88	111	86	0	100	44.7	90
78-11-07	0	100	1.72	39	34.3	62	206	56	0.57	86	51.5	81
79-07-10	0	100	0	100	7.5	82	33	86	0.50	63	20.1	90
79-07-17	0	100	0.19	80	3.8	92	40	84	0.19	89	3.8	97
79-07-24	0	100	0.25	88	5.1	93	46	87	0	100	12.7	95
79-07-31	0	100	0.22	82	2.2	96	20	91	0.87	62	8.7	96
79-08-14	0	100	0.33	92	3.3	99	20	98	0	100	9.9	98
79-08-21	0	100	0.64	47	12.9	86	19	96	0.32	92	13.0	93
79-08-28	6.2	-495	2.05	36	13.7	93	72	90	0.34	95	13.7	97
79-09-04	2.7	26	0.56	61	11.1	86	44	89	0.27	94	55.6	70
79-09-11	0	100	0.50	48	5.6	87	17	92	0.94	57	17.0	88
79-09-18	0	100	0.16	76	3.2	90	19	89	0	100	6.3	95
79-11-06	0	100	1.19	61	8.0	93	40	91	0	100	23.9	91
79-11-13	0	100	0.64	56	12.9	81	100	62	0.32	70	19.4	89
80-07-22	0	100	0.63	93	12.6	96	57	96	0	100	0	100

(a) Concentrations less than detection limit set to zero for load calculations
(b) Load left in pond calculated by:

$$\% \text{ Load Left in Ponds} = \left(\frac{I-O}{I} \right)$$

where I = Load at SS-23 + Load at SS-24 + Load at SS-17
O = Load at PS-12

(c) These dates were the only dates in the historic data base that SS-17, SS-23, SS-24 and PG-12 were sampled on the same day.

lead, and total zinc for SS-17, SS-23, SS-24, and PS-12 collected on the same day. These data were used to calculate the values in Table 3-7.

The historic data show that pond metal removal efficiency was significantly reduced in the winter for all metals measured and the reduction of pond efficiencies began as early as November. The historical data also indicate that the late summer high efficiencies continued into September. Comparison of historic and RI data shows similar trends in removal efficiencies and indicates that total loads released to the Clark Fork River decreased during the RI.

3.1.1.4 Pond Sediment

Bottom sediment samples collected in 1975 from Pond 3 were analyzed for total metals. Samples were taken at several depths in an effort to obtain the variation in concentrations with depth. Results from this work by Neher and Weisel (1977) are presented in Table 3-8.

3.1.2 Pond System Operation

The Warm Springs Ponds were constructed to limit the downstream effects of mining in Butte. They are standing bodies of water in an otherwise flowing stream. Water (primarily from Silver Bow Creek) enters the pond system containing contaminants derived from

TABLE 3-8
HISTORIC SEDIMENT ANALYSES FOR TOTAL METALS (µg/g dry weight)
AT VARIOUS DEPTHS IN WARM SPRING TREATMENT POND 3[a]

DEPTH (cm)	Cd	Cr	Cu	Fe	Pb	Zn
10	647.4	120	17660	264800	580	34603
20	670.2	100	17550	292280	600	39475
30	623.4	80	12970	281300	870	35948
40	724.1	100	21430	300680	1120	36554
50	422.6	100	19840	230610	1210	25870
60	321.0	60	13300	186940	720	18118
70	322.8	80	11460	233410	800	26985
80	485.0	100	12100	222210	950	23807
90	463.4	80	8450	237020	820	22290
100	408.1	100	8860	241900	1120	25246
110	51.0	60	6460	244360	1030	22649

(a) Source: Neher and Weisel (1977)

several sources (Appendix A, Surface Water and Point Source Investigation). After impoundment and treatment in the ponds, water is discharged to the upper Clark Fork River and is regulated under Montana Pollution Discharge Elimination System (MPDES) permit number MT-0000183. The permit sets maximum concentration levels for several metals, sulfate, TSS, and pH as shown in Table 3-9.

TABLE 3-9
MAXIMUM ALLOWABLE CONCENTRATIONS FOR THE POND 2 DISCHARGE (PS-12)

Parameter (mg/L)	Daily Maximum	Instantaneous Maximum
Total Cu	0.20	0.09
" Zn	0.50	0.30
" Fe	2.20	2.20
" As	0.050	0.050
" Pb	0.10	0.10
" Cd	0.010	0.010
" Hg	0.001	0.001
Sulfate	625	625
TSS	45	45
pH (s. u.)	6.5-9-5	6.5-9.5

The parameters listed are of concern for the protection of the Clark Fork River, and the Warm Springs Ponds are designed to minimize impacts of these constituents. The ponds were designed to be large basins with very slow moving water of high pH. The high pH would enhance the precipitation of many dissolved metals, and the low water velocity would allow aggregation and settling of precipitates, adsorbants, and mineral sediment. The Pond 3 discharge removes the upper-most layer of decanted water at the furthest point from the inlet. Pond 2 acts both to further settle and precipitate metals and as a back-up for occasional upsets in Pond 3.

The discharge from Pond 2 is monitored twice per week by the permittee, Anaconda Minerals Company (AMC).

3.1.2.1 Pond System Description

The Warm Springs Pond system consists of three large settling ponds, numbered chronologically and consecutively from north to south as Pond 1, Pond 2, and Pond 3. Between Ponds 2 and 3 a series of small ponds have been created for wildlife habitat and are referred to as the "Wildlife Ponds". The Opportunity Ponds, southwest of the Warm Springs Ponds, are tailings impoundments associated with the smelter in Anaconda. Figure 3-1 is a schematic representation of the pond system's inflows and outflows and shows average high and low flows at each station measured and average flow for the RI period.

Pond 3 is currently the most active part of the treatment system. Silver Bow Creek water enters Pond 3 (SS-20) from the south, through a gated structure at the upper pH station (SS-19). The structure controls flow into Pond 3 and allows peak flows to be diverted around the treatment pond system and directly into the Mill-Willow Bypass. Seepage water from the Opportunity Tailings Ponds is transported under the Mill-Willow Bypass and into Pond 3 from the west (SS-23 and SS-24). Pond 3 discharges into Pond 2 through two decant towers at the northern end of Pond 3 (SS-21 and SS-22). Pond 3 also discharges a small amount to the Wildlife

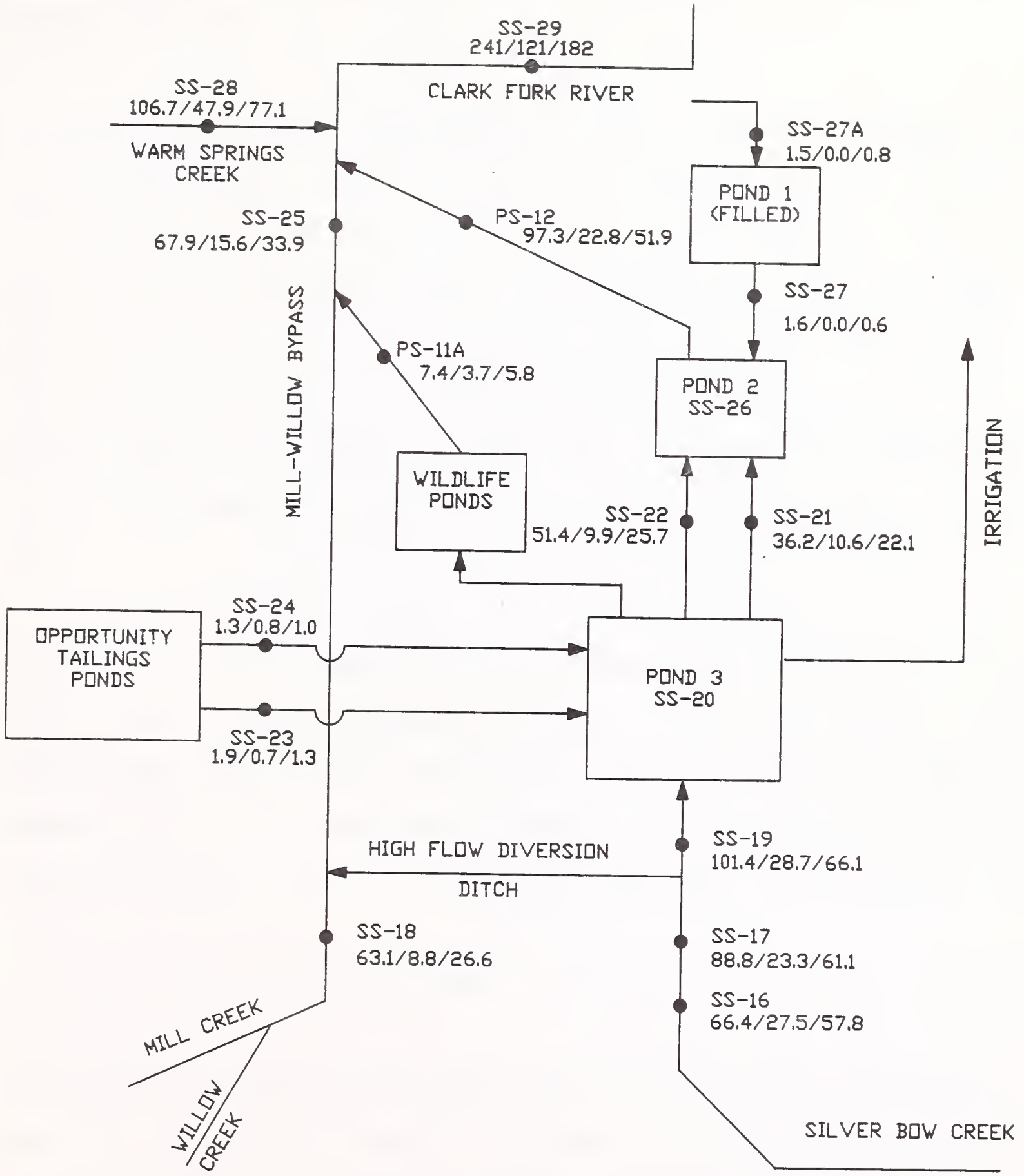


FIGURE 3-1

SCHEMATIC DIAGRAM OF WARM SPRINGS PONDS AREA
SHOWING AVERAGE FLOWS
(HIFLOW/LOWFLOW/RI) IN CFS.

Ponds via syphons, which is then discharged to the Mill-Willow Bypass (PS-11A).

In addition to water from Pond 3, Pond 2 receives seepage water pumped from Pond 1 (SS-27) and seepage water pumped from below Pond 1 (SS-27A). Another small inflow to Pond 2 is Whitcraft Gulch from the hills to the east. Pond 2 discharges through the lower pH station (PS-12), and the discharge water combines with water from the Mill-Willow Bypass and Warm Springs Creek to form the Clark Fork River. Pond 2 is nearly filled with sediment and precipitates. Pond 1 is filled and acts only to collect seepage water from Pond 2.

Figure 3-1 can be used to discern the relative contributions of flow volume at each measured station. The major inflow is from Silver Bow Creek (SS-19), providing 97% of the flow into the ponds. Discharges from the ponds are primarily through the Pond 2 discharge (90.5%), though 9.5% is discharged through the Wildlife Ponds.

3.1.2.2 Pond System Management

Management of the Warm Springs Ponds affects their performance and the effectiveness of metals removal. Adjustments include pond elevation control and lime addition to control pH.

Elevation in Pond 2 is controlled by a board weir in the outlet spillway structure, while in Pond 3, board weirs in the two decant

towers are used. Levels are kept low through early spring to accept higher spring runoff flows, and raised in summer to increase retention time. In late fall (usually late October), pond levels are raised to allow ice formation on the entire pond. After 3-4 inches of ice has formed, pond levels are dropped rapidly to anchor the ice mass in order to prevent damage to dikes and decant structures by floating ice masses. Ice build-up is cleared daily from weirs and inlets.

Additionally, elevation in Pond 2 is lowered in late summer to anchor floating plant masses and prevent them from blocking the discharge structure. Pond 1 elevation is kept low during most of the year to prevent excess seepage. During winter, the elevation is raised to prevent pump freezing.

Burnt lime is added to the incoming Silver Bow Creek water at the Pond 3 inlet structure (SS-19) to control pH and facilitate precipitation of metals in the ponds. Lime addition is determined by the pH at the outlet from the ponds (PS-12), with the target pH in the range 8.5 to 8.7, and generally is required only during the winter. Lime also is added to the water being pumped from Pond 1 to Pond 2 and is activated by pump operation.

3.1.3 Pond System Characterization

This section describes observations and interpretations about the Warm Springs Ponds system. It includes discussions of contaminant

removal efficiences, postulated removal mechanisms, bottom sediment composition, and the predicted operating life of the ponds.

3.1.3.1 Removal Efficiencies

Two approaches were taken to estimate the efficiency of the Warm Springs Ponds at removing incoming contaminant loads: the mass balance study, performed during the summer of 1985; and a study of inflow/outflow loads and concentrations over the entire RI period (December 1984 to September 1985). The mass-balance study provides more accurate data for calculation, but only considers sulfate, phosphate, iron, zinc, and copper and is limited to summer efficiences, which are much higher because of lower flows and higher pH. The inflow/outflow study utilized all parameters regularly measured (sulfate, copper, zinc, iron, arsenic, lead, cadmium) over the whole RI period, accounting for both winter and high flow conditions, but it is not as accurate as the mass balance study and should be considered a close approximation of efficiency.

Mass Balance Study

The mass balance study was undertaken to determine the efficiency of the Warm Springs Ponds in the removal of metals. Additional goals were the determination of phosphate removal efficiency and pond seepage quantification. The study took place only during the period from June to mid-September 1985. Equations and theory pertinent to the mass balance study are explained in Section 2.3.2.2.

Pond efficiencies were determined for the combined pond system shown in Figure 2-4. Table 3-10 sumarizes the average efficiencies for the total mass balance study period. Calculations for the final period (early September) assume no changes in constituent concentrations in the ponds, because no pond samples were taken after the end of August. This introduces minimal bias, because water quality varied little over the course of the mass balance investigation.

TABLE 3-10
EFFICIENCY OF WARM SPRINGS PONDS
DURING MASS BALANCE STUDY (JUNE 1-SEPTEMBER 15,1985)

	Pond System (a)	Pond 2 (a)
Sulfate	-6	-9
Cu (T)	97	42
Cu (D)	>51	---
Zn (T)	96	41
Zn (D)	>89	---
Fe (T)	89	55
Fe (D)	>44	---
Total Phosphorus(b)	72	-4
Ortho Phosphorus(b)	59	-105

Note:

(a) Percentage of inflow loads removed
(b) Change in pond storage term is not known.

The efficiency of sulfate removal was calculated (Table 3-10) along with metals removal efficiency because sulfate apparently acts non-conservatively at some times of the year. Sulfate data suggest very little sulfate was lost or added during the mass balance study period. However, during dry weather (mid-June through the end of July), sulfate appears to decrease; for the remaining wetter part

of the study period, sulfate increased in the pond system. This difference suggests sources of sulfate within the pond system.

One possible source of sulfate detected in the pond area is the pump back from Pond 1 to Pond 2 (SS-27). Since this pump back operated on an irregular schedule, its loading to the ponds is difficult to estimate. It was not operational during either the July or August samplings, and it probably operates less than half-time. Taking half-time operation as the maximum pumping rate, SS-27 would contribute no more than 15 acre-feet of water in a 15-day period. Calculating loads from this assumption and water quality sample data from June yields negligible loads of all metals when compared to other inputs. However, the sulfate load contributed by SS-27 could be as large as 32,000 pounds in a 15-day period. This load is about 10% of other inflow loads to the pond system, but it is not large enough to account for at least two of the periods of sulfate gain in the ponds (early August and early September). Other potential sources of sulfate are surface runoff from tailings within the pond area, oxidizing pond bottom sediments, and ground-water inflow.

Metals removal efficiencies were calculated with the formula given in Section 2.3.2.2. The pond water can act as a source of metals if there is a decrease in storage or a decrease in concentration in the ponds, hence some of the efficiencies calculated by this formula exceed 100%. However, these anomalies are balanced over time by increases in the storage term. Therefore, long-term pond efficiencies

are always less than 100%, even if calculated efficiencies occasionally exceed 100% on a short-term basis.

Total metals were efficiently removed during the study period in the Warm Springs Ponds: 89% of the total iron, 96% of the total zinc, and 97% of the total copper (Table 3-10). The efficiencies of removal were consistently high throughout the mass balance study period, except that the total iron efficiency was only 68% during the first period in June. This reduced efficiency occurred during a high-flow period when sediment transport was at a peak in Silver Bow Creek.

Dissolved metals data could not be meaningfully interpreted in many cases because much of the data were below analytical detection limits. In the case of dissolved iron, values less than the detection limit occurred in the outflows, allowing a lower bound to the efficiency to be calculated. This calculation shows great variability from period to period due to the closeness of the reported values to the detection limit. However, the 44% average efficiency for dissolved iron removal is probably a result of the flocculation and settling of iron in the ponds. Similiar analyses showed lower bounds of removal at 89% for dissolved zinc and 52% for dissolved copper, over the study period (Table 3-10).

Phosphate data were not collected from the Opportunity Pond discharges or within the Warm Springs Ponds. An accurate mass balance for these contituents cannot be calculated. However, since the

outflow loads are markedly lower than the inflow loads, estimating the efficiency is valid. Table 3-10 shows that 72% of the total phosphorus and 59% of the orthophosphate were removed during the mass balance study period.

The calculation of Pond 2 efficiency separately shows that Pond 2 improves water quality under low flow, daytime, summer conditions. Sulfate shows a slight gain, which is probably not significant over the mass balance period. Pond 2 provides a 55% removal of inflowing total iron, 41% removal of inflowing total zinc, and 42% removal of inflowing total copper (Table 3-10). The data for dissolved metals are incomplete because concentrations in both inflows and outflows were often less than the analytical detection limits. No trend is discernible for dissolved metals removal on the dates the efficiencies were calculated.

Pond 2 behaved differently than Pond 3 in the removal of total phosphorus and orthophosphate. Although the ponds as a whole removed total phosphorus and orthophosphate, Pond 2 increased concentrations of these constituents during some periods. This is especially apparent during July and August when these constituents increased by factors of up to four times. Comparing the gains in Pond 2 for orthophosphate to those for total phosphorus (Table 3-10) shows that the orthophosphate increases account for the increases in total phosphorus.

Pond Seepage

Calculating pond seepage requires evaporation and precipitation data from the pond study area. Table 3-11 shows the net pond evaporation and the pond seepage for the study area. Evaporation includes evaporation from Pond 3, Pond 2, the Wildlife Ponds, and evapotranspiration from the marsh and the irrigated grain acreage. Evapotranspiration was calculated from the 525 acres of willows and marsh grasses that are also included in the study area. If this area consumes water at the same rate as alfalfa, it could have caused as much as 200 acre-feet of water loss in a 15-day period in July. During August and September, precipitation exceeded evaporation, thus the 525-acre area would not have increased the evaporation factor by this much because precipitation of this area would partially runoff into the ponds.

Seepage calculated in this mass balance study is the unaccounted remainder after inflows, outflows, change of storage, evaporation, precipitation, and evapotranspiration are calculated. This quantity varies considerably from period to period. It is generally positive (net outflow) during dry weather and negative (net inflow to ponds) during wet weather, suggesting a source of water exists within the study area. The source of water in wet weather may be the unaccounted-for precipitation on the 525 acres of willows and marsh grasses. A small bias also is introduced by ignoring the Pond 2 pump-back (SS-27); however, because the likely maximum amount of inflow was 15 acre-feet in a 15-day period, it is not

TABLE 3-11
NET POND EVAPORATION AND SEEPAGE
FOR MASS BALANCE STUDY PERIOD

Period	Net Evaporation(a)	Seepage(a)
June 6-15	201	-144
June 16-30	354	142
July 1-15	333	53
July 16-31	304	319
August 1-15	109	-83
August 16-31	215	-34
September 1-15	112	-35
Total Period	1,631	218

(a) Values in acre-feet

large enough alone to explain the apparent gains of water in August shown in Table 3-11. Additional potential sources of water within the pond system are Silver Bow Creek alluvial discharges at the upper end of Pond 3 and unmeasured surface inflows such as Whitcraft Creek.

Although the seepage estimate could be refined (probably reduced) if better data were available for the 525 acres, seepage appears to be rather small. Total calculated seepage from both ponds over a three-month period is 218 acre-feet, which is equivalent to a combined seepage rate of less than 2 cfs from both ponds.

Inflow/Outflow Study

This study calculated efficiencies using only inflow and outflow loads and concentrations. No adjustments were made to account for evaporation, seepage, change in storage volumes, or evapotranspiration, thus it is not as accurate as the mass-balance study. However, the only significantly large component of the above list is the change in storage volume term, and this averages out over the course of the study. Additionally, the full suite of surface-water parameters can be evaluated and efficiencies calculated for the entire RI study period.

Table 3-12 lists average removal efficiencies and the amount of material removed during the RI period. The table represents reductions in loads and excludes Run 1 (Dec. 3-5, 1984) because the water balance for this run is in error by 150%. The calculations include all measured inflows and outflows to the ponds, and have been divided into individual pond evaluations. Table 3-12 integrates high and low flow, as well as summer and winter conditions, and is representative of overall pond operational efficiency. The table shows that overall pond efficiencies are markedly lower than those calculated in the mass-balance study. Cadmium and lead removals are fairly high; copper, zinc, and iron removals are near 60%; arsenic removal is 36%. Sulfate appears to have a slight gain (3.3%) in the pond system, but this gain is less than the confidence level ($\pm$3.5%) and may not be significant.

TABLE 3-12
INFLOW/OUTFLOW STUDY EFFICIENCIES
ON THE WARM SPRINGS PONDS[a]

	Pond System[b]		Pond 3[b]		Pond 2		
	lbs	% of inputs	lbs	% of inputs to Pond 3	lbs	% of inputs to Pond 2	% of all inputs
Sulfate	-232,111	-3.3	409,161	5.9	-641,271	-12.9	-9.2
Cu	8,531	65.0	7,506	57.2	1,025	20.5	7.8
Zn	22,428	60.4	18,483	49.8	3,944	27.5	10.6
Fe	52,586	59.9	44,285	50.4	8,301	26.7	9.5
As	674	36.3	635	34.2	39	3.2	2.1
Pb	681	72.8	601	64.2	80	25.2	8.6
Cd	93	87.0	44	41.2	49	81.6	45.8

Note:

(a) Calculated on runs 2-15 (Dec 26 - Aug 27) only, using all measured inflows and outflows.

(b) Runs 2-6 used input from station SS-16 due to the frozen stream at SS-19.

The table also shows the difference in efficiencies between Pond 3 and Pond 2. Pond 2 is significantly less efficient in removing all contaminants except cadmium. It also appears to be a polishing pond, reducing metals levels an additional 10%, except for cadmium. The table also indicates that Pond 3 removes 6% of the input sulfate, but Pond 2 adds 9% to the water, so the observed overall gain of 3% may be a real phenomenon.

Several errors may be introduced by using loads in these calculations, mostly due to inaccurate water balances from the change in storage term. To check this possibility, efficiencies were recalculated using concentrations only and compared to those calculated using

loads. Table 3-13 presents the results of this check and illustrates that over the entire RI period, this error averages out and the two calculations are very close.

TABLE 3-13
COMPARISON OF LOAD AND CONCENTRATION DECREASES, FOR THE WARM SPRINGS POND SYSTEM OVER THE RI PERIOD

	% Load Removed	% Concentration Decrease
Sulfate	-3.3	-17.4
Cu (T)	65.0	64.3
Zn (T)	60.4	61.6
Fe (T)	59.9	57.8
As (T)	36.3	33.0
Pb (T)	72.8	73.7
Cd (T)	87.0	87.3

Accuracy was additionally checked by comparing inflow/outflow efficiencies to those derived from the mass balance study for the time period and the parameters that overlap in the two studies. Results of this comparison are presented in Table 3-14. The table shows that the results of the studies are not significantly different and that the inflow/outflow study method results can be used to quantitatively characterize pond system efficiencies.

The efficiency of metals removal in the Wildlife Ponds was calculated and compared to those for Pond 2 (Table 3-15). Efficiencies in the table are concentration reductions, with the inlet concentration for the Wildlife Ponds set as the concentrations measured in Pond 3 (SS-20). The performance of the Wildlife Ponds far exceeds that of Pond 2 for most contaminants, and is somewhat better than Pond 3

TABLE 3-14
COMPARISON OF MASS-BALANCE STUDY AND INFLOW/OUTFLOW STUDY EFFICIENCIES FOR THE PERIOD JUNE-SEPTEMBER 15, 1985

	Inflow/Outflow Study Efficiency[a]	Mass-Balance Study Efficiency [a]
Sulfate	+7	-6
Cu (T)	88	97
Zn (T)	95	96
Fe (T)	86	89

Note:

(a) Percent of inflow loads.

TABLE 3-15
COMPARISON OF WILDLIFE PONDS AND POND 2 EFFICIENCIES[a]

	Wildlife Ponds[b]	Pond 2
Sulfate	-20.9	-3.0
Cu (T)	65.9	28.5
Zn (T)	78.4	36.5
Fe (T)	73.5	32.9
As (T)	17.3	4.9
Pb (T)	66.3	31.0
Cd (T)	100.0	84.6

Note:

(a) Percent reduction in concentrations.
(b) Calculated using Pond 3 (SS-20) for inflow concentrations and PS-11A for outflow.

efficiencies for metals (except arsenic). This performance is probably due to the Wildlife Ponds' construction (dual cells and greater depth), the very low inflow rate (approximately 6 cfs), and the dredging of older tailings before installation of the ponds. They act as excellent settling ponds, with a longer retention time and slower moving water than in Pond 2. These factors should be considered if construction or renovation of treatment facilities is considered as a remedial option.

3.1.3.2 Metal Removal Mechanisms

The mechanisms of metal removal by the Warm Springs Ponds significantly affects both observed efficiencies and metal stabilization and permanent removal from the system. Three mechanisms play a role in metals removal by the Warm Springs Ponds, as described in Section 2.3.3. Some of these mechanisms and their relative importance with respect to seasonal (winter vs. summer) and hydrologic (high vs. low flows) variations were observed and measured during the RI period. The RI data indicated that both ponds behave similarly, so the following discussion applies to both Ponds 2 and 3. The most significant influence on outflow metal concentrations is flow rate. High flows deliver more material to the ponds, allow less settling time, and do not allow the ponds to be a quiescent settling basin. Hydrologic control is prominent on metals that tend to occur in the solid phase. The spring runoff period generally has the highest inflow and outflow metals' concentrations and the lowest removal efficiencies for the entire RI period. Sulfate tends to behave inversely with flow rate: higher outlet concentrations during low flows, and lower during high flows. This behavior is probably due to a dilution effect by surface waters lower in groundwater-derived sulfate.

The influence of seasonal pH variation was apparent during the RI on metals occurring in the dissolved phase. Dissolved zinc is clearly affected by lower pH in the winter (Runs 3-6 in this RI). Dissolved copper and cadmium are less sensitive but still exhibit

higher concentrations during the winter low-pH period. These observations are expected from equilibrium calculations (Section 2.3.3). Zinc remains in a dissolved form at winter pH levels (6.5-8.5) and precipitates at summer levels (8.5 -10.0). Cadmium (dissolved) behaves similarly to zinc. Dissolved copper precipitates at a lower pH than zinc, but is affected by very low pH (<7.5) occurring in the ponds during January and February 1985. Table 3-16 compares pond outlet concentrations for the various seasonal conditions described previously.

The RI data indicate that algae may have an effect on metal stabilities in the pond system. During the summer period, when algae growth is normally greatest, a general rise in pH was observed in the ponds. The increase is most probably caused by increased algal photosynthesis, taking carbon dioxide from the water and shifting the carbonate equilibrium. This shift allows the pH to rise to values as high as 10.

Arsenic behavior is different than the other metals. At lower pH and during much of the year, arsenic behaves as a solid species, probably adsorbed to the abundant iron hydroxides or other adsorbants. However, at higher pH's reached during the summer (9.0 - 10.1), arsenic appears to be released by the ponds. This is probably a desorption phenomenon and is predicted at higher pH's. Arsenic is stable in the ponds as an anionic species ($HAsO_4^{2-}$) and behaves inversely to cationic species; low pH causes greater adsorption, and higher pH, less adsorption (Misra and Tiwari 1963).

TABLE 3-16
AVERAGE OUTLET CONCENTRATIONS FROM
THE POND SYSTEM DURING THE RI

	Winter (Runs 3-6) Low Flow - Low pH		Spring (Runs 8-10, 12) High Flow		Summer (Runs 13-15) Low Flow - High pH	
	Avg. outlet conc. (mg/L)	% of input	Avg. Outlet conc.(mg/L)	% of input	Avg. outlet Conc.(mg/L)	% of input
Sulfate	149.7	120.5	112.2	113.8	128.6	117.3
Cu(T)	.067	47.4	.075	43.4	.020	18.5
(D)	.010	26.0	.021	36.7	0	0
Zn(T)	.326	73.6	.146	37.3	.026	7.6
(D)	.292	89.4	.038	14.4	.001	1.6
Fe(T)	.522	41.3	.649	50.4	.122	21.1
(D)	.012	2.1	.021	48.8	.009	28.3
As(T)	.009	66.3	.013	52.3	.017	91.8
Pb(T)	.004	46.8	.005	23.4	.001	20.3
Cd(T)	.0003	33.2	.0001	4.5	.0001	13.1
pH (s.u.)	7.6	--	8.0	--	9.3	--
Flow (cfs)	51.1	--	105.2	--	35.5	--
Hardness (mg/L as $CaCO_3$)	230	--	168	--	119	--

Algae may also be important in the Warm Springs Ponds through bioaccumulation. The ability of phytoplankton and periphyton species to concentrate metals is well documented (Appendix D, Part 1, Algae Investigation). Iron, copper, and zinc are required micronutrients for algae (Nichols 1973) and are assimilated into algal biomass. A more important accumulation mechanism is probably adsorption on the cell surface or mucilagenous sheath secreted by numerous species (Jennett, et al. 1983). The bioaccumulation mechanism may be especially important during algae blooms that have been reported to occur. Some of these have occurred during the winter when the pH in the pond system was relatively low and the amount of dissolved metals high. These dissolved metals then could be available for assimilation by the algae and transport out of the system.

3.1.3.3 Pond Bottom Sediments

Sampling of bottom sediments from both Ponds 2 and 3 allowed limited characterization of the solids comprising these sediments, as well as interstitial water present in the sediments. Pond bottom data are presented in Attachment VIII.

Pond Sediments

Analysis of the pond bottom sediments show considerable enrichment in metals concentrations when evaluated against background lake bed sediment data taken from Moore (1985). Pleistocene lake bed sediments are used to provide a comparative basis only. As expected,

pond bottom sediments are enriched over background by several orders of magnitude. Mean values of pond sediments are presented in Table 3-17.

The table also shows that the sediments in Pond 3 tend to have slightly higher metals concentrations than sediments in Pond 2, with the exception of lead. These extreme concentrations indicate that 20-30% of the pond bottom materials may be some form of metal-liferous sediment.

TABLE 3-17
COMPARISON OF WARM SPRINGS POND
AND BACKGROUND SEDIMENTS (a)

Parameters	Background Pleistocene Missoula Lake Beds (b)	Pond 2 (SS-26)	Pond 3 (SS-20)
As	23	294	422
Cd	2.5	103	193
Cu	27	3940	5170
Pb	19	542	183
Fe	17600	71000	95300
Zn	70	12100	32300

Note:

(a) Mean values, in ppm dry weight.
(b) Source: Moore 1985.

High metals concentrations in the bottom sediments in the Warm Springs Ponds have at least three possible sources: deposition of mineral sediments, including tailings materials, that enter the system by way of Silver Bow Creek; deposition of precipitated metal compounds; and deposition of metal-enriched algae. All these processes may be occurring, causing the extreme concentrations of

metals in the pond sediments. The presence of these metal-enriched sediments on the bottoms of Ponds 2 and 3 is significant. Any remediation plan for the area must consider them as a potential source of metals.

The total organic carbon (TOC) content of the pond bottom material varied widely, from 0.18% to 2.89%, with Pond 2 having a generally higher TOC content. These results suggest that Pond 2 contains a larger algae population than does Pond 3, which is consistent with algae counts made in the spring of 1985 by the Montana Department of Health and Environmental Sciences (MDHES) Water Quality Bureau (WQB) (see Appendix D, Algae Investigation). They also suggest that metals concentration by algae could be a component in the deposition of metals.

Bottom Sediment Interstitial Water

Dissolved metal concentrations from pore water samples are presented in Table 3-18. These concentrations are markedly lower than might be expected from the bottom sediment values listed in Table 3-17.

These dissolved metals concentrations do not exceed those expected from calculated theoretical equilibrium concentrations at the measured pH. However, dissolved iron and arsenic concentrations in ground water downgradient of Pond 1 are about ten times higher than bottom sediment pore water concentrations with similar pH. The increase in iron and arsenic concentrations in seepage water

Table 3-18
COMPARISON OF PORE WATER IN POND SEDIMENTS (units mg/L)

Parameter	Pond 2 (SS-26)	Pond 3 (SS-20)
As (Diss)	.024	.011
Cd (Diss)	.0006	.0009
Cu (Diss)	.027	<.011
Pb (Diss)	.002	<.001
Fe (Diss)	.360	<.01
Zn (Diss)	.191	.002

from the ponds may be occurring along the flow path. Those increases may be due to strong reducing conditions found within, and presumably beneath, the bottom sediment, or may be due to even higher metals concentrations in the sediments beneath those sampled.

3.1.3.4 Useful Operating Life

The total operational life of the ponds is the amount of time required to fill them with sediment from the Silver Bow Creek drainage. The useful operating life will be somewhat less than the total life due to a variety of factors affecting removal efficiencies as the ponds fill. Several assumptions have been made in calculating the total operational period:

- First, for calculation purposes, sediment yield of the Silver Bow Creek drainage was set at 0.1 acre-ft/sq.mi/year, although the SCS value is shown as <0.1 (USDA, 1977).

- Second, the area of the Silver Bow Creek drainage was determined to be 424 square miles. However, this includes 13 square miles that drain into the Yankee Doodle Tailings impoundment (no outlet), and 51 square miles drained by Mill and Willow Creeks which bypass the pond system. Subtracting these areas yields a drainage basin area of 360 square miles.

- Third, the bathymetric survey (Cashell Engineers 1985) yields a storage volume of 4294 acre-ft remaining in Pond 3 and 759 acre-ft in Pond 2; for the purpose of these calculations, Pond 2 is assumed to be full, with little or no remaining storage capacity.

- Finally, metal loads deposited in the ponds are calculated to be less than 0.02 acre-ft/yr, which is an insignificant contribution compared to total sediment loads (36 acre-ft/yr).

The calculation is as follows:

$$\text{Total Operational Life Span (yrs.)} = \frac{4294 \text{ acre-ft}}{(0.1 \text{ acre-ft/sq.mi./yr}) \times 360 \text{ sq.mi.}}$$

Using the above assumptions, a remaining total life span of 119.3 years is calculated.

The calculation above assumes Silver Bow Creek's entire sediment load is delivered to the Warm Springs Ponds. In fact, at flows above approximately 700 cfs, Silver Bow Creek is routed around the pond system into the Mill-Willow Bypass (U.S. Army Corps of Engineers 1978); bypasses probably occur at much lower flows than the design bypass flow of 700 cfs. These high-flow events can account for a significant, but unknown, percentage of the total yearly sediment load delivered by Silver Bow Creek to the Clark Fork. This means that large amounts of sediment from the Silver Bow Creek drainage basin will occasionally bypass the pond system, as currently operated, thereby prolonging the pond system's life.

The calculation also assumes that 100% of the sediment delivered is trapped by the ponds. Although no data are available, the sediment trapping efficiency is likely to be somewhat lower. This factor also has the effect of lengthening the pond system's life.

The useful operating life likely will be less than the 119 years calculated above. However, without additional detailed information concerning sediment loads, particle size distribution, sedimentation rates, and efficiency/basin volume relationships for Pond 3, it is not feasible to predict efficiency reductions over time as the basin fills. However, as the ponds fill, removal efficiencies will be reduced and channeling may occur, reducing the "usefulness" of the pond system.

3.2 MILL-WILLOW BYPASS

The Mill-Willow Bypass is an artificial channel, built to allow the relatively good quality water from Mill and Willow creeks to bypass the Warm Springs Pond system. Treated water from the Wildlife Ponds (PS-11A) and Pond 2 (PS-12) discharges to the bypass, which is located between the Opportunity Tailings Ponds to the west and the Warm Springs Ponds to the east (Map 1-2, Over Size). Both of these features significantly influence water quality within the Mill-Willow Bypass.

3.2.1 Historic Data

Historic discharge measurements and water quality sampling of the Mill-Willow Bypass were performed at the mouth of the diversion just before its confluence with the Pond 2 discharge (near SS-25). The historical average discharge at this point was 38.6 cfs from 1975 to 1982. Average sulfate concentration was 260 mg/L. Average metals concentrations except copper were low at this sampling site and are approximately equal to those observed in the Pond 2 discharge. The Mill-Willow Bypass at the historic sampling point includes flow from the Wildlife Ponds discharge (PS-11A), which originates from the Warm Springs Ponds. Discharge from the Wildlife Ponds may account for some of the observed metals and sulfate in the Mill-Willow Bypass as measured above its confluence with the Pond 2 discharge.

3.2.2 RI Data

Two RI Sampling Stations were established on the bypass, one at the upper end of the bypass (SS-18), and one at the lower end (SS-25), just upstream of the confluence with the Pond 2 discharge (PS-12). The Wildlife Ponds discharge to the bypass between SS-18 and SS-25 (Figure 3-1).

Differences in flow and loads between the two stations were calculated for base-flow conditions on the bypass, taking into account loads added by the Wildlife Ponds discharge (PS-11A). Changes in loads are summarized in Table 3-19.

The increase in flow and in dissolved copper and zinc, total iron and cadmium, and sulfate indicate ground-water input. This was substantiated during the seepage runs completed on the bypass in July and August 1985, which showed increases in flow and sulfate concentration occur all along the bypass and not at any given point. A specific conductance (SC) survey of the Mill-Willow Bypass during base-flow also helped confirm ground-water input to the bypass. Specific conductance survey data are presented in Attachment IX, from a total of 33 SC transects of the bypass. These data show increasing SC in a downstream direction, higher SC values closer to the channel sides, and generally higher SC values along the western bank. Several seeps along the west bank had extremely high SC values (up to 2500 umhos/cm). The SC data indicate that poor quality water, probably with elevated sulfate, iron, and zinc, is

TABLE 3-19
INCREASES IN THE MILL-WILLOW BYPASS[a]

	Gain	% (b)
Flow	2.4 cfs	17.3
Sulfate	12906 lbs/day	180
Cu (T)	0 "	-
Cu (D)	0.13 "	310
Zn (T)	3.0 "	103
Zn (D)	2.8 "	186
Fe (T)	24.5 "	194
Fe (D)	0 "	-
As (T)	0 "	-
Pb (T)	0.05 "	74
Cd (T)	0.01 "	140

Notes:

(a) Average low flow (Runs 1,3-7, 14,15) increases measured between SS-18 and SS-25.
(b) Increase as a percentage of inputs (SS-18 and PS-11A).

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entering the bypass primarily from the west bank. The ultimate source of this ground water is likely the Opportunity Ponds.

3.3 GROUND WATER INVESTIGATION

Ground water in the vicinity of the Warm Springs Ponds was characterized through an evaluation of available historic data, data produced during this RI, and selected data generated during the Anaconda Smelter RI. An overall analysis of the ground-water system is presented following these discussions.

3.3.1 Historic Data

Historic AMC data appropriate to the RI study primarily include selected analytical data from shallow monitoring wells DW-340 and DW-401, located just east of the Opportunity Ponds berm (Map 1-2, Over Size). Historic AMC data are contained in Appendix B, Ground-Water and Tailings Investigation.

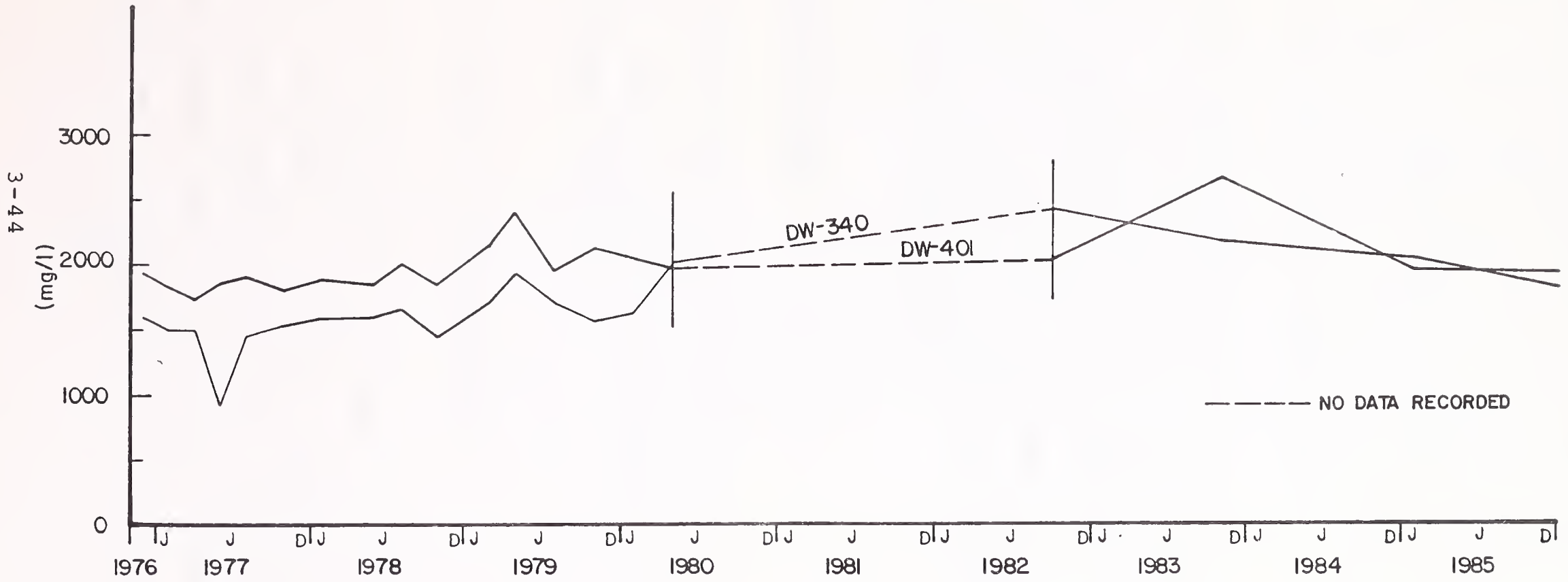
Shortcomings of historic AMC ground-water data are that metals analyses were for total metals, which are difficult to correlate with data collected during the RI. Other available historic AMC data pertinent to data analyzed during the RI include sulfate and field parameters (temperature, pH, and specific conductivity).

Figure 3-2 depicts a plot of historic sulfate concentrations in monitoring wells DW-340 and DW-401 for the period 1976 through 1985. The sulfate plots indicate that concentrations generally increased in the shallow ground-water system directly adjacent to the Opportunity Ponds from 1976 until 1982/1983, after which a gradual decline in concentration is noticeable.

These observations are qualified because historic data collection methods and associated quality assurance measures are unknown. Additionally, data apparently do not exist for the period from 1980 to mid-1982.

FIGURE 3-2

SULFATE CONCENTRATIONS IN MONITORING WELLS DW-340 AND DW-401 (1976-1985)



AMC's specific conductivity (SC) data from monitoring wells DW-340 and DW-401 over the same period of record show a generally upward trend in values from 1976 to 1984, if anomalous 1979 values are excluded (Figure 3-3). A measurable decrease in SC is notable from 1984 to 1985. The historic SC data are subject to the same quality assurance limitations as are sulfate data.

Historic metals data for AMC monitoring wells DW-340 and DW-401 are variable and erratic. Order-of-magnitude fluctuations in total metals concentrations are apparent from one sampling period to the next. Correlations between the various total metals parameters are inconsistent. For these reasons, historic AMC metals data are suspect, rendering analysis inappropriate.

3.3.2 Silver Bow Creek RI Data

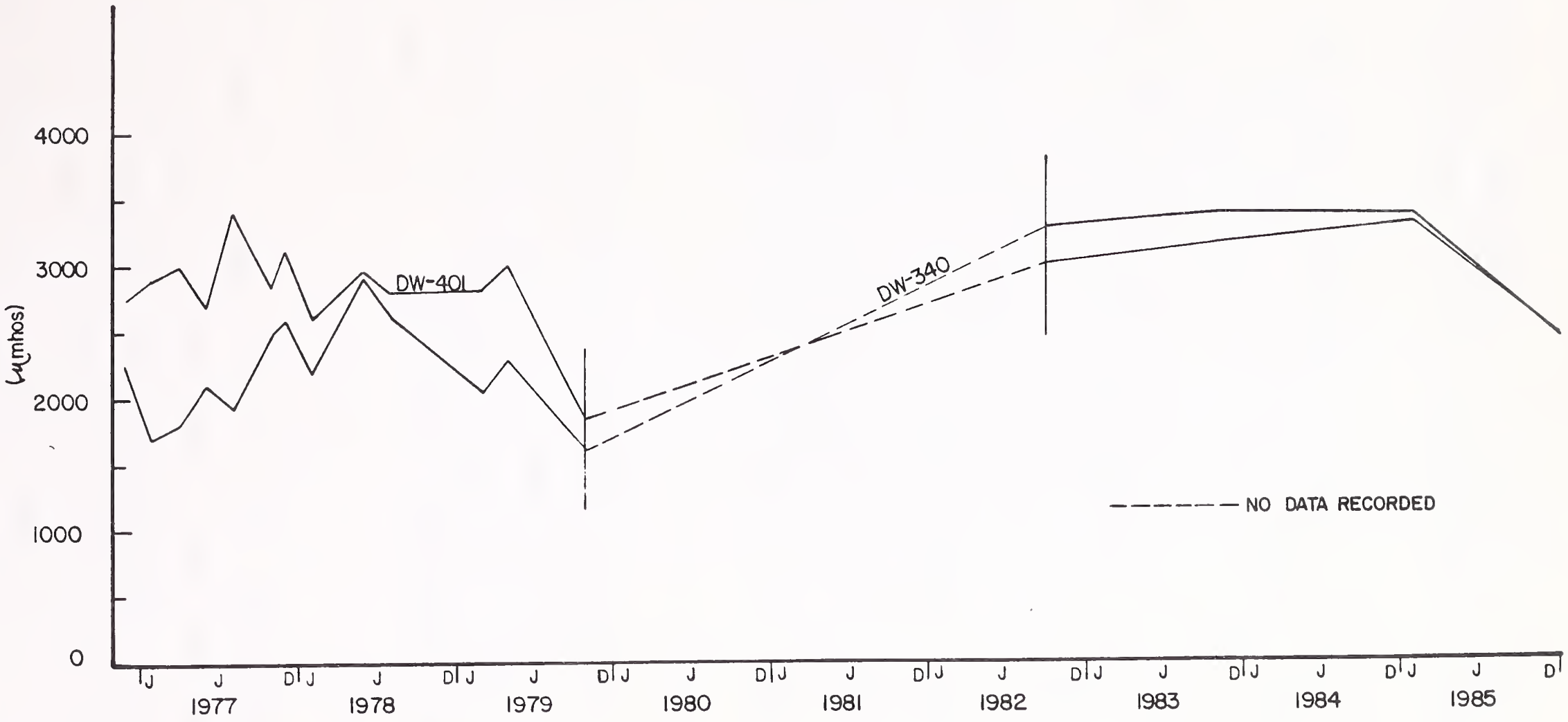
Four basic characteristics of ground water in the area are addressed: lithology and aquifer characteristics; ground-water levels; ground-water quality; and geologic materials.

3.3.2.1 Lithology and Aquifer Characteristics

Generally, lithology is characterized by relatively thin alluvium overlying a very thick sequence of Tertiary valley fill. Varying thicknesses of tailings are present throughout the area. Near-surface lithologies encountered during drilling activities typically include sand and gravel units separated by varying thicknesses of

FIGURE 3-3

SPECIFIC ELECTRICAL CONDUCTANCE IN MONITORING WELLS DW-340 AND DW-401 (1976-1985)



finer-grained material. Correlation of lithologies laterally was generally not possible owing to the heterogeneity of the deposits.

Tailing deposits and water impoundments occupy a large portion of the southern Deer Lodge Valley. Alluvium is present along modern stream channels, but is generally thin and not laterally extensive. Older and thicker deposits of glacial material are occasionally intermixed with the alluvium, which was deposited on an erosional surface of colluvial valley fill (Konizeski et al 1962). This Tertiary-age valley fill is at least 6,000 feet thick and may be much thicker in the central part of this fault-bounded valley (Noble et al. 1982). Volcanic and intrusive bedrock units underlie the valley fill, but because of their extreme depth, bedrock aquifers probably do not directly influence the near-surface hydrogeologic system.

Existing well logs indicate several water-bearing zones at different depths which are at least partially interconnected. These are probably glaciofluvial sand and gravel lenses with limited hydraulic communication between them. Intervening impermeable material is probably locally present.

Lithologies encountered during drilling for this investigation (Attachment IV) were typically comprised of sand and gravel units separated by varying thicknesses of silt and clay. Direct correlation of lithologies between drill holes is not possible, due to the heterogenous nature of the deposits. Iron-stained sand units,

typified by an orange color, were encountered in monitoring wells WSP-2 and WSP-3 (just north of the Pond 1 berm). The presence of the iron-stained sand units correlates directly with elevated dissolved iron concentrations in ground water sampled in these zones.

Alluvial water-bearing zones correlated directly with sand and gravel units encountered during drilling. No aquifer testing was performed in this area during the Silver Bow Creek RI.

3.3.2.2 Ground-Water Levels

Ground-water levels in the study area are significantly influenced by the presence of the Opportunity Ponds and the Warm Springs Ponds. These large surface-water bodies cause localized and regional ground-water mounding, which creates a complex potentiometric surface in the area. A detailed evaluation of ground-water flow directions requires additional subsurface data. Several ground-water characteristics can be determined using ground-water levels measured during the RI:

- A significant ground-water system enters the area from the adjacent Opportunity Ponds/Warm Springs Creek vicinity. This ground water moves to the northeast and is apparently partially intercepted by the Mill-Willow Bypass in the vicinity of Warm Springs Pond 3. The gradient of this ground-water component is approximately 0.8%.

- The regional ground-water gradient through the Warm Springs Pond system is to the north at about 0.4%.

- Artesian conditions were encountered during drilling of monitoring well WSP-1, located south and upgradient from the pond system. Increasing hydraulic head with depth is also evident based on water-level data collected from dual-completion monitoring well WSP-2 (located below Pond 1) and between monitoring wells WSP-4 and WSP-5 (located approximately 0.3 mi. below the Pond 1 berm) (Map 1-2 Over Size). The magnitude of increasing hydraulic head differences with depth in these wells ranges from about 2 feet at WSP-2 to less than 0.3 feet between wells WSP-4 and WSP-5.

Two major ground-water systems combine in this area; the Silver Bow Creek system moves from south to north through the Warm Springs Ponds system, and the Warm Springs Creek/Opportunity Ponds system enters from the southwest. The convergence of these two systems forms the Clark Fork River alluvial system near the northern end of the study area.

Ground water moving from the Opportunity Ponds area is a significant component of the ground-water regime in this area. If permeabilities in the Opportunity Ponds/Warm Springs Creek and Silver Bow Creek alluvial systems are assumed to be similar, then more ground water probably moves through the Opportunity Ponds/Warm Springs Creek system because its ground-water gradient is nearly twice that of

the Silver Bow Creek system. The influence of the Opportunity Ponds ground-water system is readily visible in the Mill-Willow Bypass during baseflow conditions in the form of seeps on the west side of the bypass.

The Silver Bow Creek alluvial system also is influenced by the Warm Springs Ponds system. Increased hydraulic head with depth is present both above and below the pond system. This increase indicates the ground-water system has an upward component, at least locally. A downward component of ground-water movement is also likely beneath the ponds because of ground-water mounding.

3.3.2.3 Ground-Water Quality

Water quality data for ground-water samples collected in the Warm Springs Ponds area are presented in Attachment III. Ground-water quality was evaluated during the RI by field data collection and by laboratory analyses of samples collected from a network of 19 monitoring wells. The majority of the wells are located downgradient of the Opportunity Ponds and the Warm Springs Ponds. One monitoring well is located upgradient of the Warm Springs Ponds, and a domestic well used for monitoring is completed in bedrock east of the pond system.

Field Parameters

Field data collected in the Warm Springs Ponds area during the ground-water investigation of the RI included pH, specific electrical conductivity (SC), temperature, oxidation-reduction potential (Eh), and dissolved oxygen (DO). Three parameters (pH, SC, and temperature) were measured for all ground-water samples collected. The other field parameters were measured intermittently on selected wells.

Field data suggest wells can be categorized based on location and completion depth. Field parameters further suggest that ground-water quality between the Opportunity Ponds and the Warm Springs Ponds is different from ground water elsewhere in the area. Data also indicated a ground-water quality difference between wells completed deeper than 50 feet below ground surface and those shallower. Likewise, monitoring wells located downgradient from Warm Springs Pond 1 exhibit field parameters peculiar to that area, as do wells completed in bedrock adjacent to the site.

Table 3-20 presents averages and ranges of values of measured field parameters for shallow versus deep wells located between the Opportunity Ponds and the Warm Springs Ponds. The table suggests that relatively poor quality water occurs at shallower depths in ground water in this area, evidenced by elevated SC values. Temperature generally increases with depth, pH decreases about 0.3 s.u., and

higher oxidation potential appears with depth in the ground-water system. Dissolved oxygen data shows no significant trends.

TABLE 3-20
MINIMUM-MAXIMUM AND AVERAGE VALUES OF FIELD PARAMETER DATA IN THE OPPORTUNITY POND AREA

Field Parameter	Monitoring Wells >50 ft. deep [a] (Range/Avg.)	Montoring Wells <50 ft. deep [b] (Range/Avg.)
Temperature (°C)	7.0-10.0/8.4	6.0-8.0/7.2
pH (s.u.)	7.0-8.0/7.4	6.4-7.5/6.9
SC (umhos/cm @25°C)	330-1820/990	1470-3370/2260
Eh (millivolts)	+60-+425/+180	-40-+140/+50
DO (mg/L)	1.0-4.7/2.8	1.2-6.0/2.6

(a) Includes wells DW-341, DW-405, DW-411, DW412, and DW-415 (Map 1-2, Over Size).

(b) Includes wells DW-340, DW-401, DW-403, DW-404, DW-414, and DW-416 (Map 1-2, Over Size).

Monitoring wells located below Warm Springs Pond 1 include WSP-2 through WSP-5 (Map 1-2, Over Size). Wells WSP-2 and WSP-3 are dual completion wells; WSP-4 and WSP-5 are located immediately adjacent to each other and are completed deep and shallow, respectively. Drilling and sampling field parameter data from these wells suggest vertical variability in the ground-water system in this area, similar to that previously described for the Opportunity Ponds area. Relatively poor quality ground water, as characterized by high SC values, is present in the upper part of the aquifer. However, the depth at which relatively low SC values are encountered, 20 to 40 feet below ground surface, appears to be shallower than in the Opportunity Ponds area. A reducing zone also appears to be present

at shallow depths in the area downgradient of Pond 1. This zone is indicated by negative Eh values obtained at monitoring wells WSP-2B and WSP-5.

Other observations of measured field parameters for the area below Pond 1 include the following: (1) ground-water temperature ranges from 5° to 9°C, with the warmest water occurring at depth; (2) pH values are typically near-neutral, ranging from about 6.5 to 7.5 s.u.; and (3) dissolved oxygen values are generally within the 1 to 3 mg/L range.

Monitoring well WSP-1 and domestic well DW-408 (Map 1-2 Over Size) are located upgradient from, and adjacent to, the Warm Springs Ponds, respectively. These wells exhibit relatively low SC values compared to other monitoring wells sampled, and pH values are nearly neutral. Eh and DO concentrations in WSP-1 are relatively high, indicative of oxidizing conditions and plentiful dissolved oxygen in the aquifer at shallow depths.

Metals

Metals data collected during the RI included analyses for dissolved arsenic, cadmium, copper, iron, lead, and zinc.

Dissolved arsenic concentrations were elevated (from approximately 0.2 to 0.24 mg/L) in shallow monitoring wells (DW-340 and DW-401) located immediately downgradient of the Opportunity Ponds, and in

shallow monitoring wells WSP-2B and WSP-5, located downgradient of the Warm Springs Ponds (Map 1-2, Over Size). Other measured arsenic concentrations were near or below the method detection limit. All four wells exhibiting elevated dissolved arsenic concentrations are less than 25 feet deep.

In the Opportunity Ponds area, the presence of dissolved arsenic appears to be localized and apparently is associated with the Opportunity Ponds themselves. Dissolved arsenic below Warm Springs Pond 1 appears more widespread laterally, extending at least as far as monitoring well WSP-5, located approximately 0.5 miles below Pond 1. The source of dissolved arsenic is within the Warm Springs Pond system, indicated by greater concentration at WSP-2B than at WSP-5 (0.244 mg/L versus 0.027 mg/L). Elevated dissolved arsenic concentrations below both the Opportunity Ponds and Warm Springs Ponds appear to be a near-surface phenomenon, as deeper adjacent wells have no detectable dissolved arsenic.

Dissolved cadmium concentrations were near or below detection for almost all ground-water samples collected in the RI. A measurable but insignificant concentration of 0.0014 mg/L was determined for a sample collected at monitoring well WSP-2B, located below the Pond 1 berm (Map 1-2, Over Size).

Elevated concentrations of dissolved copper were evident in monitoring wells DW-401 (located below the Opportunity Ponds) and in monitoring well WSP-2B (located immediately below the northern berm

of Warm Springs Pond 1) (Map 1-2, Over Size). A dissolved copper concentration of 0.03 mg/L was reported for monitoring well DW-401 and a range of 0.016 to 0.038 for monitoring well WSP-2B. Samples from other wells had no detectable dissolved copper. Both wells exhibiting measurable dissolved copper are relatively shallow and also contain elevated concentrations of other metals. Dissolved copper was not detected either downgradient from these wells or in adjacent deep wells. For this reason, the ponds are believed to be localized sources for dissolved copper. Widespread groundwater contamination does not appear to be evident.

Several monitoring wells sampled during the RI contained significant concentrations of dissolved iron. The greatest concentrations of dissolved iron were measured in monitoring wells WSP-2B (62.9 mg/L), DW-401 (119 mg/L), and DW-340 (43.9 mg/L) (Map 1-2, Over Size). Other parameters also exhibited elevated concentrations in these three shallow wells. Several other wells sampled contained concentrations of dissolved iron in the range of 1 to 4 mg/L. These included monitoring wells DW-403, DW-404, and WSP-5. Monitoring well WSP-3A contained dissolved iron concentrations in the 0.1 to 1.0 mg/L range. The remaining wells sampled contained dissolved iron concentrations less than 0.1 mg/L.

Significant dissolved iron concentrations appear to correlate with other elevated metals parameters measured in several shallow wells (e.g. dissolved arsenic and dissolved copper). However, measurable dissolved iron concentrations appear more widespread, being present

both in wells north of the Opportunity Ponds and north of the Warm Springs Ponds. High dissolved iron concentrations are most prominent immediately below the two pond systems, indicating a source of the metal within both pond systems.

Dissolved lead concentrations were elevated in two wells sampled during the RI: DW-340 and WSP-4 (Map 1-2, Over Size). Other wells sampled were at or below detection limits. The concentration of dissolved lead in monitoring wells DW-340 was 0.025 mg/L and WSP-4 was 0.019 mg/L, during one sampling episode each. These values appear anomalous, however, because dissolved lead concentrations were an order-of-magnitude less in both wells during other sampling episodes. These anomalies are probably caused by sampling and/or analytical errors and may not reflect actual conditions.

Dissolved zinc concentrations were measurable in several monitoring wells sampled in the Warm Springs Ponds area:

- WSP-2B, WSP-5, DW-401 (0.1 to 0.4 mg/L); and
- WSP-3B, DW-340 (0.02 to 0.1 mg/L).

Those monitoring wells exhibiting greater than 0.02 mg/L dissolved zinc are relatively shallow (less than 40 feet deep). Monitoring wells located downgradient of the Opportunity Ponds show rapidly decreasing dissolved zinc concentrations away from the pond system. Dissolved zinc concentrations in shallow ground water below the Warm Springs Ponds do not decrease laterally as markedly as below the Opportunity Ponds. The greatest concentrations of dissolved

zinc appear to be associated with the area below the eastern half of the Pond 1 berm and extending at least as far as monitoring well WSP-5, located approximately 0.5 miles downgradient of Pond 1 (Map 1-2, Over Size).

Common Ions

Common ions analyzed from ground-water samples collected during the RI included calcium, potassium, magnesium, sodium, sulfate, chloride, bicarbonate alkalinity, and carbonate alkalinty. Figures 3-4 and 3-5 are trilinear diagrams for the December 1985 sampling episode, depicting common ion percentages for wells in the vicinity of the Opportunity Ponds and the Warm Springs Ponds, respectively.

Figure 3-4 suggests a definable grouping of shallower (less than 50 feet deep) and deeper (greater than 50 feet deep) monitoring wells in the vicinity of the Opportunity Ponds. Shallow wells tend to exhibit high percentages of sulfate plus chloride and calcium plus magnesium. Deeper wells contain a higher percentage of carbonate plus bicarbonate and a percentage of calcium plus magnesium similar to that in the shallow wells. The major cation in both shallow and deep ground water is calcium, whereas the major anion is sulfate in shallow water and bicarbonate in the deeper ground-water zones.

Monitoring wells located in the Warm Springs Pond vicinity tend to group on the trilinear diagram based on location rather than depth

Sample Date: Dec. 1985
Monitoring well locations shown on
Map 1-2 (over size)

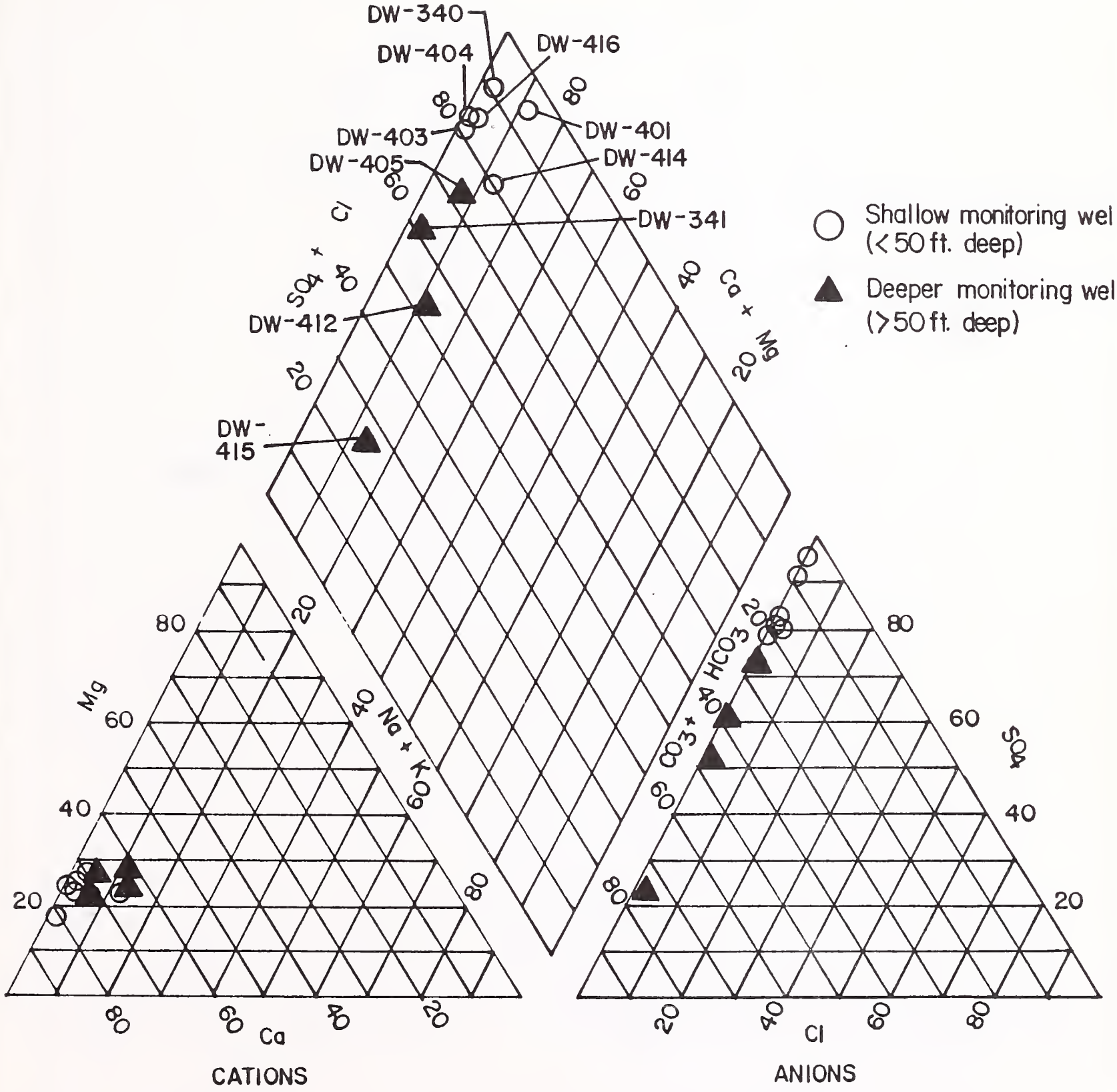


FIGURE 3-4

TRILINEAR DIAGRAM OF GROUND-WATER QUALITY IN THE VICINITY OF THE OPPORTUNITY PONDS

Sample Date: Dec. 1985

Monitoring well locations shown on Map 1-2 (over size).

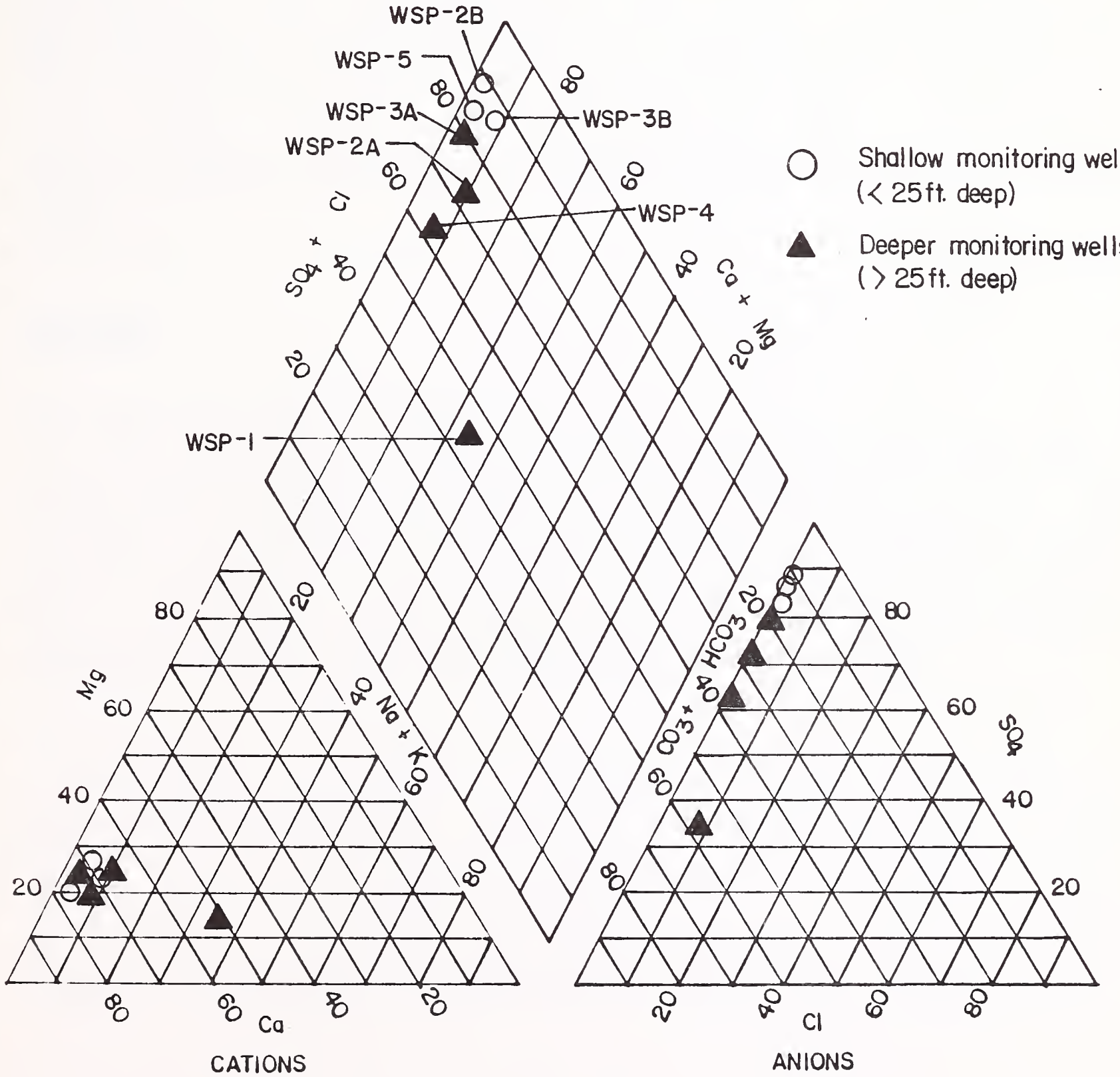


FIGURE 3-5

TRILINEAR DIAGRAM OF GROUND-WATER QUALITY IN THE VICINITY OF THE WARM SPRINGS TREATMENT PONDS

of the well (Figure 3-5). Monitoring well WSP-1 is located upgradient of Pond 3 and exhibits significantly different water chemistry than those monitoring wells located downgradient of Pond 1. Downgradient wells contain a much greater percentage of sulfate and calcium ions than does upgradient well WSP-1. Monitoring well WSP-1 exhibits a higher percentage of bicarbonate than downgradient wells. Figure 3-5 also shows that shallow wells below Pond 1 contain a higher percentage of the sulfate ion than adjacent deeper wells.

Fluoride

Fluoride concentrations were elevated in shallow ground-water monitoring wells relative to adjacent deeper monitoring wells. The greatest concentrations of fluoride were found in monitoring wells DW-401 and WSP-2B. The presence and concentration of fluoride correlates directly with the occurrence of heavy metals.

A significant concentration of fluoride (1.3 mg/L) enters the Warm Springs Pond ground-water system, as measured at WSP-1. This correlates well with observed water chemistry in upgradient areas and is possibly associated with the hot springs in the vicinity of Gregson (see Appendix B, Ground-Water and Tailings Investigation).

3.3.2.4 Subsurface Materials Chemistry

Analysis of the chemistry of geologic materials sampled in the observation wells is important in that it may provide insight into observed local ground-water quality. Elevated metal levels in sampled materials could result from deposition of tailings or waste material, from aerial (Anaconda Smelter) outfall of contaminants, or from migration of metals from a remote contaminant source. Remote contaminant sources could include the Warm Springs Pond bottom sediments, Silver Bow Creek-Clark Fork River tailings deposits, tailings deposits from the Old Works smelter, or from aerial deposition of smelter emissions.

To determine if elevated metal concentrations in sediments would likely influence (or result from) contaminated ground water, it is first essential to identify background levels of metals. A number of values for geochemical background exist in the literature for soils, sediments, and whole rock samples.

Only three RI samples had total metal levels which clearly exceeded both global and local geochemical background levels. These samples were taken from the two-to-three foot depth in wells WSP-1, WSP-2, and WSP-4. The surface sample from WSP-3 immediately below Pond 1 did not have elevated metals. All deeper samples appeared to be at background levels. Wells WSP-1, WSP-2, and WSP-4 are similar in that all of them lie in the Silver Bow Creek-Clark Fork River floodplain. The location, depth, and elevated pyritic sulfur

concentration of these samples suggest that the source of elevated metal content is flood deposition of tailings.

Despite the elevated total concentration of metals in the surficial sediments in wells WSP-1, WSP-2, and WSP-4, it is doubtful that these materials have contributed to adverse ground-water quality. Water soluble concentrations of cadmium, copper, iron, manganese, lead, and zinc are in the normal range for soils, probably due to the alkaline pH (7.6 to 8.1) of these materials. These pH's are higher than those found in tailings deposits further upstream on Silver Bow Creek. Liming of the pond system or depositional influence from carbonate rocks exposed in Warm Springs Creek drainage may explain the higher pH levels.

3.3.3 Anaconda Smelter RI Data

Several constant discharge and recovery tests were performed on wells located just west of the Warm Springs Ponds in conjunction with the Anaconda Smelter RI. Calculated transmissivity values ranged from 16.3 to 5900 gallons per day per foot (gpd/ft.) for AMC monitoring well numbers 77 through 81 (Tetra Tech 1985). This range in transmissivity values is probably also representative of the Silver Bow Creek alluvial system in the Warm Springs Pond area, given the lithologic similarities.

Ground-water quality data have been collected adjacent to the Opportunity Ponds recently by TetraTech in conjunction with the

Anaconda Smelter RI/FS. These data are contained in the TetraTech (1985) report for the Anaconda Smelter RI.

Sulfate concentrations measured in shallow wells DW-340 and DW-401 are much greater than the sulfate concentrations of the two surface-water discharges from the Opportunity Ponds (SS-23 and SS-24). This indicates the probable source of increased sulfate load in the Mill-Willow Bypass is ground water associated with the Opportunity Ponds system.

Table 3-21 is a comparison of near-synchronous quality data collected from the same monitoring wells during this RI and the Anaconda Smelter RI in late 1985. In general, concentrations of measured parameters were similar between the two laboratories involved. Because of this, interpretations of ground-water quality in the area between the Opportunity Ponds and Warm Springs Treatment Ponds is the same as that described previously.

3.3.4 Ground-Water System Analysis

Nearly all wells sampled exceeded the Federal secondary drinking water standard for sulfate of 250 mg/L. The highest sulfate concentrations were typically in the 1000 to 2000 mg/L range and generally were associated with shallow ground water downgradient from each pond system and extending down-valley.

TABLE 3-21
COMPARISON OF SELECTED GROUND-WATER QUALITY DATA FROM THE SAME
WELLS INCLUDED IN THE SILVER BOW CREEK AND ANACONDA SMELTER DATA BASES

CROSS-REFERENCE WELL NOS.		SULFATE		DISS. Fe		DISS. As		Diss. Zn		DISS. Cu	
(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
DW-340	AMC-29	1830	2180	43.9	30.9	0.0052	0.009	0.035	0.041	<0.024	0.013
DW-341	AMC-30	250	1240	0.026	2.7	<0.0023	0.003	<0.015	0.016	<0.011	0.010
DW-401	AMC-28	1960	2190	119.0	96.0	0.029	0.024	0.247	0.202	0.030	0.012
DW-403	AMC-70	1100	1160	3.34	2.43	<0.0023	<0.003	<0.011	0.014	<0.024	<0.006
DW-404	AMC-71	1040	1160	1.22	0.745	<0.0023	<0.003	<0.011	0.016	<0.024	<0.006
DW-412	AMC-80	195	212	0.026	0.028	<0.0023	<0.003	<0.015	0.005	<0.011	<0.006
DW-414	AMC-78	1040	1320	0.077	0.075	<0.0023	<0.003	<0.015	0.028	<0.011	0.018
DW-415	AMC-77	50	50	<0.030	0.691	<0.0023	<0.003	<0.011	0.016	<0.024	0.007
DW-416	AMC-79	1070	1190	0.026	<0.02	<0.0023	<0.003	<0.015	0.014	<0.011	<0.006

(1) Data from Silver Bow Creek RI; Sample Date: Dec/1985
(2) Data from Anaconda Smelter RI; Sample Date: Oct/1985

The most significant metals found in the RI ground water are dissolved iron (maximum of 199 mg/L), and dissolved arsenic (maximum of 0.165 mg/L). These parameters are prominent in shallow ground water downgradient of the Opportunity Ponds and Warm Springs Pond 1. Elevated dissolved iron and arsenic concentrations in ground water emanating from the Opportunity Ponds area are relatively localized.

A metals plume, of which dissolved iron and dissolved arsenic are most prominent, also appears to be present downgradient of Warm Springs Pond 1. Other metals (e.g. dissolved zinc, dissolved copper) are also part of the plume, although concentrations of these parameters are below drinking water standards. The source of metals for the plume is apparently within the Warm Springs Pond system, because water quality upgradient of the pond system is generally good.

The ground-water contaminant plume below Pond 1 appears to be limited to the upper portion of the aquifer; the width of the plume extends from approximately the middle of Pond 1 to the eastern extent of the unconsolidated material aquifer, a distance of about 0.5 miles. The plume extends downgradient at least 0.5 miles; the total extent and areal configuration is unknown. Federal drinking water standards for arsenic are exceeded in ground water near the Pond 1 berm, and for iron throughout the plume area. As described previously, sulfate concentations are elevated throughout the ground-water system below Pond 1.

Surface-water quality samples collected from seepage water pumped from below Pond 1 back into Pond 1 (sample site SS-27A) also contain elevated iron and arsenic concentrations. These concentrations are further evidence that some metals concentrations are elevated below the eastern portion of the Pond 1 berm.

The ground-water plume containing elevated dissolved iron and dissolved arsenic is located along the eastern margin of the valley bottom, because of preferential ground-water movement in that area. This historic Silver Bow channel was located near the eastern portion of the Pond 1 berm prior to construction of the impoundment. Alluvial gravels associated with the original stream system may provide a path for preferential ground-water movement. Because of this, the plume may extend downgradient as "fingers" or lobes of contaminants.

Another possible explanation of the location of the ground-water plume is the surface drainage pattern and topography inside Pond 1, which drains all seepage from Pond 2 to the northeast corner of Pond 1. This drainage, coupled with the pump-back of seepage from below Pond 1, creates a body of poor quality water in the northeast corner of Pond 1 which may be seeping through the berm in this area.

Sulfate, dissolved iron, and dissolved arsenic in ground water moving northward from the Warm Springs Pond system appear to have little impact on the receiving Clark Fork River, owing to dilution

from better quality water from Warm Springs Creek and the Clark Fork River itself (see Appendix A, Surface-Water and Point-Source Investigation). Surface-water dilution of ground-water entering the river is prominent even during baseflow conditions, because of the great disparity between the quantity of surface water in the Clark Fork River compared to ground-water inflow.

Degraded ground water emanating from beneath the Opportunity Ponds affects the Mill-Willow Bypass by contributing a significant sulfate load to the receiving stream. This phenomenon is readily visible along the Mill-Willow Bypass (during baseflow) as seeps along its western bank. The Warm Springs Ponds also impact the Mill-Willow Bypass to some extent, although not as visibly as the Opportunity Ponds.

Historic ground-water data suggest recent improvement in ground-water quality downgradient of the Opportunity Ponds. But because of the unknown integrity of the historic data, detailed analysis of the data was not attempted beyond that already described for sulfate and SC.

Comparison of analytical data from the SBC RI and the Anaconda Smelter RI for samples collected from the same wells indicates no significant variability in the data. Interpretations of ground-water quality characteristics were supported by review of the Anaconda Smelter RI ground-water quality data.

DRAFT

4.0 CONCLUSIONS

4.1 SEVERITY AND EXTENT OF CONTAMINATION

The pumpback to Pond 1, the Mill-Willow Bypass, and the Opportunity Pond discharges are all open water bodies accessible to the public, and may represent a risk to human health from surface-water contamination. Federal primary drinking water standards for metals were not exceeded in the two discharges from the Warm Springs Treatment Ponds (PS-11A and PS-12) during the RI and generally were not exceeded in the ponds themselves (SS-20 and SS-26; Table 4-1). The standard for lead (0.05 mg/L) was exceeded by both Opportunity Pond discharges on one date. The drinking water standard for arsenic (0.05 mg/L) was exceeded at both stations on the Mill-Willow Bypass during a relatively high-flow event. This arsenic exceedance probably did not originate from contamination in Silver Bow Creek. The Pond 1 Pumpback (SS-27A) was the only station to regularly exceed the primary drinking water standard for arsenic.

Chronic aquatic life water-quality criteria (four-day average concentrations) for cadmium, copper, lead, and zinc were exceeded throughout the Warm Springs Ponds occasionally during the RI study period (Table 4-2). The acute aquatic life criterion (one-hour average concentration) for copper is usually exceeded in the ponds, and the acute criterion for zinc is occasionally exceeded in the ponds but not in the ponds' discharges. These conclusions are based on total metals analyses and may therefore exaggerate the

TABLE 4-1
PRIMARY DRINKING WATER STANDARDS EXCEEDENCES IN THE
WARM SPRINGS PONDS AREA
(concentrations in mg/L)

			Mill-Willow Bypass		Opportunity Ponds Discharges			Pond 1 Pump-back	
Run #	Date	Parameter	SS-18	SS-25	SS-23	SS-24	SS-26	SS-27A	Standard[a]
1	12/05/84	Pb			0.129	0.192			0.05
3	01/30/85	Cd					0.012		0.01
5	02/27/85	As						0.097	0.05
7	03/27/85	As						0.091	0.05
8	04/10/85	As						0.128	0.05
9	04/23/85	As						0.108	0.05
12	06/05/85	As	0.105	0.120					0.05

Note: (a) USEPA, 1985a
USEPA, 1985b
USEPA, 1985d

TABLE 4-2
AQUATIC LIFE STANDARD EXCEEDENCES IN THE
WARM SPRINGS PONDS AREA (a)

	N	Exceeding Chronic Standard(b)					Exceeding Acute Standard(c)				
		As	Cd	Cu	Pb	Zn	As	Cd	Cu	Pb	Zn
SS-20	15	0	1	14	5	13	0	0	13	0	2
SS-21	18	0	2	17	5	18	0	0	17	0	2
SS-22	19	0	0	18	5	16	0	0	18	0	0
SS-26	15	0	4	14	6	11	0	2	14	0	4
PS-11A	18	0	0	9	1	3	0	0	8	0	0
PS-12	18	0	0	15	3	11	0	0	13	0	0
SS-18	14	0	0	10	1	2	0	0	8	0	0
SS-25	14	0	0	10	1	10	0	0	7	0	0

Notes:

(a) Aquatic life standards for freshwater as published by United States Envrionmental Protection Agency 1986 and 1985(a-d). Metals measured as total since total recoverable data are not available.

(b) Chronic criteria are defined as 4-day average concentration, not to be exceeded once every 3 years on the average.

(c) Acute criteria are defined as 1-hour average concentration, not to be exceeded once every 3 years on the average.

aquatic life toxicity problems in the Warm Springs Ponds. Fish were observed in Pond 3 and the Wildlife Ponds during the study period; hence, the use of total metals concentrations to determine aquatic life toxicity may overestimate toxicity for adult trout. However, the presence of fish does not necessarily mean that fish can successfully perform all life functions (e.g., reproduction).

The Mill-Willow Bypass also exhibits chronic aquatic life toxicity for copper and zinc and acute toxicity for copper. The incidence of chronic toxicity of zinc increases greatly along the course of the Mill-Willow Bypass.

Ground water in the Warm Springs Ponds area is contaminated down-gradient of the Warm Springs Ponds and the Opportunity Ponds. Federal drinking water standards are exceeded for sulfate, arsenic, iron, and fluoride in these areas. No domestic wells are in the vicinity of the contaminated ground water, so no apparent or immediate threat exists to public health.

The Warm Springs Ponds sediments contain some of the highest concentrations of toxic metals to be found in the RI study area and pose a potential threat to water quality in the Clark Fork River for an indefinite period.

4.2 SOURCES OF CONTAMINATION

The Warm Springs Ponds were constructed to control metals contamination delivered by Silver Bow Creek and the Opportunity Ponds that otherwise would flow into the Clark Fork River. They should act, therefore, as a sink for contamination rather than a source. However, several measured and potential sources of contamination to the Clark Fork River exist in the Warm Springs Ponds area.

4.2.1 Measured Sources of Contamination

4.2.1.1 Surface Water

The Warm Springs Ponds generally act as a sink for sediment, total metals, dissolved metals, and nutrients. However, the ponds are not 100% efficient in trapping metals delivered by Silver Bow Creek and the Opportunity Ponds discharges and can be considered a source of contamination to the Clark Fork River. Another source of contamination to the Clark Fork is the Mill-Willow Bypass which receives contaminants, apparently from ground water, along its course and delivers them to the Clark Fork River. These sources are summarized and compared in Table 4-3 regarding contaminant loads delivered to the Clark Fork.

TABLE 4-3
SOURCES OF CONTAMINATION TO THE CLARK FORK RIVER[a]

	Pond 2 Discharge (PS-12)		Wildlife Ponds Discharge (PS-11A)		Mill Willow Bypass (SS-25)[b]	
	Load (lbs)	%[c]	Load (lbs)	%[c]	Load (lbs)	%[c]
Flow	--	40	--	4	--	1
Sulfate	10,175,025	46[d]	1,173,975	5	2,911,413	13[d]
Cu(T)	4,834	50[d]	194	2	774	8[d]
Zn(T)	14,138	74[d]	300	2	1,242	6[d]
Fe(T)	45,135	45[d]	829	1	10,146	10[d]
As(T)	879	38	110	5	17	1
Pb(T)	424	64[d]	6	1	0	0
Cd(T)	10	43	0	0	3	13[d]

(a) Includes measured loads delivered during the entire RI period, December 1984 - August 1985.

(b) Corrected for upstream loads (SS-18 and PS-11A).

(c) Percentage of inputs to the Clark Fork River.

(d) Percent load significantly higher than percent flow, indicating water quality is degraded.

The table shows that the Pond 2 discharge was the largest contributor of contaminant loads to the Clark Fork River during this RI and significantly degraded water quality with sulfate, copper, zinc, iron, and lead. The Mill-Willow Bypass degraded water quality with sulfate, copper, zinc, iron, and cadmium. Surface water in the Clark Fork River is degraded by these two sources, although they are not the ultimate sources of contamination. Silver Bow Creek and the Opportunity Pond discharges are sources to the Pond 2 discharge, and ground water is the source of contaminants to the Mill-Willow Bypass.

4.2.1.2 Ground Water

Ground-water quality data indicate that the Warm Springs Ponds are sources of ground-water contamination. Shallow ground water below the Pond 1 berm (WSP-2B) contains elevated levels of most constituents measured, when compared to ground water sampled upgradient of the ponds. The ground-water quality observed in shallow (<25 feet deep) ground-water monitoring wells downgradient of Pond 1 is comparable to surface water observed in the Pond 1 pumpback (SS-27A), which recycles seepage water that collects below the Pond 1 berm back to the pond system. The similarity of the water quality of these two sources indicates that seepage water is not completely contained by the pumpback, and that it moves north from the ponds as ground water.

The calculated direction of travel of contaminated ground water downgradient of the Pond 1 berm is to the north, at a gradient of about 0.4%. No hydraulic data are available for this area with which to calculate the rate of movement of the contaminants. Monitoring well WSP-5, located about 0.5 miles north of Pond 1 and near the Clark Fork River, also contains levels of dissolved metals well above background levels. This measurement suggests that contaminated ground water is present at least this far north. Surface-water data presented in Appendix A, Surface-Water and Point-Source Investigation, show no measurable effects of contaminated ground-water inflow to the Clark Fork River.

Contaminated ground water below Pond 1 appears to occur mainly in the eastern portion of the valley bottom. Two factors may contribute to this occurrence. First, the eastern portion of the valley contains the alluvial gravels of the historic Silver Bow Creek channel, which may allow preferential ground-water movement in the area. Second, water is ponded in the northeast corner of Pond 1, and its presence is maintained by the Pond 1 pumpback. The presence of this body of water may locally increase the hydraulic gradient and therefore the rate of ground-water movement, in the eastern portion of the valley below the Pond 1 berm.

Other evidence of ground-water contamination from the Warm Springs Ponds is found in the Mill-Willow Bypass. A specific conductance (SC) survey of the Mill-Willow Bypass found highly conductive water near both banks of the stream. Chemical analyses of surface-water samples collected in the Mill-Willow Bypass show increases in sulfate, total iron and cadmium, and dissolved copper and zinc in this reach. Although bank erosion and channel sediments could be contributing some of the observed gains, concentration and flow increases are observed even at the lowest flows, suggesting ground-water inflow has a significant impact on water quality in the Mill-Willow Bypass.

The specific conductance survey suggested that ground-water contamination is entering the Mill-Willow Bypass primarily from the Opportunity Ponds, and in less significant amounts from the Warm

Springs Ponds. This observation is confirmed by ground-water quality data, which indicates the presence of degraded ground-water quality in the area east and northeast of the Opportunity Ponds. This ground-water system moves to the northeast and at least partially intersects the Mill-Willow Bypass.

4.2.2 Potential Sources of Contamination

4.2.2.1 High Flow Bypasses

The Warm Springs Ponds are not designed to contain major flood events. A bypass channel constructed upstream of the Warm Springs Ponds was designed to divert Silver Bow Creek flows greater than about 700 cfs around the ponds and directly into the Mill-Willow Bypass (U.S. Army Corps of Engineers 1978). From the Mill-Willow Bypass, the water continues untreated into the Clark Fork River.

The inlet structure to the Warm Springs Ponds is gated just below the diversion ditch. Debris can collect on the gates and cause water to back up, possibly causing failure of the dike and bypass of the ponds at flows much less than 700 cfs; for example, the dike at the head of the diversion ditch washed out when flow into the ponds was only 185 cfs, on June 2, 1985. Silver Bow Creek water probably bypasses the Warm Springs Ponds an average of once per year. No water quality samples were taken on Silver Bow Creek during a period when the ponds were bypassed; however, historic data have shown dramatic increases in TSS and most metals in the

Clark Fork River following a bypass event. During high-flow conditions that cause the diversion ditch to become functional, the Warm Springs Pond system is ineffective in protecting the Clark Fork River from contaminated water from Silver Bow Creek.

4.2.2.2 Pond Failure

The 100-year flood was estimated by Hydrometrics (1983a) to be 3600 cfs, and the pond structures would probably withstand a flood of that magnitude. However, during floods slightly larger than the 100-year flood, risk of pond failure increases significantly. At flows greater than 4000 cfs on Silver Bow Creek, the diversion structure at the upper pH shack would no longer function reliably and the full flood would possibly enter the Mill-Willow Bypass through the diversion ditch (IECO 1981). This flood probably would cause failure of at least one of the pond berms and loss of the contents of that pond (U.S. Army Corps of Engineers 1978). Pond 3 could fail directly when its outflow reached 5600 cfs, and a flow of 7000 cfs would overtop both Ponds 2 and 3, causing their failure (IECO 1981).

Failure of the ponds could also occur if an earthquake weakened the pond embankments. IECO (1981) estimated that the Continental Fault east of Butte could produce an earthquake of Richter magnitude 6.9, which would be sufficient to cause failure of the embankments. The study also found that 3- to 4-foot berms placed at the toes of

the unstable sections of the pond embankments would improve the safety factor to an acceptable level.

Failure of the Warm Springs Ponds embankments would release large amounts of mining and milling wastes to the Clark Fork River. Under those conditions, the Warm Springs Ponds would become a major source of contamination.

4.2.2.3 Pond Life Expectancy

As the ponds fill, their capability to trap sediment and precipitate metals will be reduced, and Silver Bow Creek will receive less and less treatment as it flows into the Clark Fork River. As the ponds reach their capacity, they may begin to act as a source of contamination. Previously deposited material could be eroded gradually by the shifting channel within the filled ponds. Sediment yield calculation for the Silver Bow Creek drainage estimates the remaining life for Pond 3 at approximately 120 years. This calculations assumes no major changes in the ponds' operation or design for the next 100 years.

4.2.2.4 Recharge Through Streambank Tailings

Large quantities of tailings with elevated metal levels have been deposited along the Silver Bow Creek-Clark Fork River flood plain. Depth of the tailings varies from near zero to six feet or more.

In the wells sampled, the solubility of metals in these deposits appears fairly low due to the high pH levels. Based on that limited sampling, ground-water recharge or surface-water percolation through the surficial tailings appears not to constitute potential contaminant source to ground water. However, if low pH or low Eh conditions exist in a portion of these deposits, metal solubilities may be greatly increased and may allow contaminant migration into ground water.

4.3 POND SYSTEM

Pond system performance calculated for the RI study period showed a variety of trends which were consistent with earlier studies. During the summer the ponds were very efficient at removing most contaminants from the influent water, because of lower flow rates which allow settling and deliver lower contaminant loads, and higher pH in the ponds which cause precipitation of dissolved metals and is probably related to increased algal activity. The high pH also appeared to liberate some arsenic, possibly by desorption.

Winter data show the ponds were much less efficient. Lower pH levels allowed some dissolved copper, zinc, and cadmium to travel through the pond system without being precipitated and removed.

Higher flows during the spring significantly lowered pond efficiencies for most metals by both delivering higher contaminant loads and reducing residence times. Solid phases of copper, zinc, and iron as well as lead and arsenic were released in large quantities during this period. Sulfate reacted inversely to flow, being highest during low flows in summer and winter. Hydrologic regime is the most important mechanism governing the amount of contaminants released to the Clark Fork River by the ponds.

Algae may be important in the Warm Springs Ponds system by influencing the pH of the ponds and through bioaccumulation of metals. This was examined in the Algae Report, Appendix D, Part 1.

Pond system performance may be significantly improved by minor modifications to current operating procedures. First, a structure or method to prevent the inlet structure at SS-19 from becoming blocked by debris would prevent pond bypasses at flows lower than design (~700 cfs). This action would not prevent bypasses of extreme flows but would remedy unnecessary releases of untreated water to the Clark Fork River. Secondly, more effective pH control could increase the amount of contaminants trapped by the pond system. Wide pH fluctuations allow contaminants to travel through the ponds: low pH in winter (6.8 - 8.0) does not effectively precipitate dissolved zinc and copper, high pH in summer (9.0 - 10) allows arsenic to desorb and be released. Maintaining pH in the range of 8.0 - 9.0 all year may effectively reduce these kinds of releases.

Table 4-4 presents total loads released to the Clark Fork River by each of these mechanisms and compares them to a bypass event measured by the Water Quality Bureau (WQB) in early 1986.

TABLE 4-4
COMPARISON OF CONTAMINANT RELEASE MECHANISMS AFFECTING THE WARM SPRINGS PONDS

Event	Duration	Cu (lbs)	Zn (lbs)	As (lbs)
Winter Low pH	42 days	777	3776	105
Summer High pH	84 days	319	420	277
Spring High flow	45 days	1917	3731	333
Pond Bypass[a]	2 days	1100	1684	109

Note:
(a) Data collected by the Montana Water Quality Bureau; Feb. 25, 1986, shortly after a bypass event.

4.4 RECOMMENDATIONS

The Warm Springs Ponds require further study because the present data base does not allow a complete evaluation of the effect of a pond bypass event, the severity and extent of ground-water contamination, and the effects of pond algae on pond pH and metals transport out of the ponds. Additional pond sediment data may be necessary, and computer modelling of pond chemistry may be required.

4.4.1 Pond Bypass Event

The relationship of sediment transport to flow is roughly exponential. A very large amount of contaminants may bypass the pond

system entirely during one of these events. No data were collected during this RI that can be used to measure the amount of contaminants released and the relative importance of this annual release. Other data collected by the WQB indicate that bypasses are a major source of contaminants to the Clark Fork River (Table 4-4). At least one of these diversions should be gaged, sampled, and analyzed for total, acid soluble, and dissolved forms of aluminum, arsenic, cadmium, copper, iron, lead, manganese, and zinc. Time integration of samples would be appropriate for this sampling.

4.4.2 Ground-Water Contamination

A contaminant plume has been demonstrated by this RI downgradient from the pond system at least 0.5 miles. The downgradient and lateral extent of this plume has not been determined. To determine the extent of the contaminant plume, additional monitoring wells must be placed downgradient from existing wells and sampled.

The RI also showed that poor quality ground water enters the Mill-Willow Bypass from both sides. To quantify the inflow due to the Warm Springs Ponds, a number of piezometers should be installed along the western berms of Ponds 2 and 3. Used in conjunction with permeability data and water levels in the ponds and the Mill-Willow Bypass, these data would allow determination of flow rates through the berms.

The determination of contaminant loads to the Mill-Willow Bypass due to pond seepage would require either placement of ground-water monitoring wells at several points along the western berms of the ponds or sampling of piezometer wells.

4.4.3 Pond Algae Studies

The Algae Investigation, Appendix D, recommends algae culture experiments to determine the ability of Silver Bow Creek algae to accumulate metals. In addition to this work, field studies should be continued to determine if the algae actually transport metals out of the ponds. Knowledge of the role algae play in metals transport will assist feasibility studies applying biological water treatment to the pond system. A sampling program which includes algae counts, total suspended solids (TSS), volatile suspended solids (VSS), and total organic carbon (TOC), as well as metals analyses, should be able to demonstrate any relationship. The sampling program for algae must include sufficient baseline data to show that changes in algae counts are indeed correlated in time with water quality parameters. Measurements should be taken at the inflow to the ponds, in the ponds themselves, and at the two pond outflows.

Water samples from the Warm Springs Ponds were collected during daylight, when pH increases from carbon dioxide assimilation would be greatest. Significant pH decreases during the night may occur from algal respiration, which would be accompanied by increased

dissolved metals concentrations. The diurnal pH pattern within the pond system could be adequately determined by taking on-site hourly pH measurements for a 24-hour period. The daytime weather should be sunny to show the maximum diurnal variation. Correlations of continuous and close-term periodic pH variations within the pond system and at discharge points would provide an excellent basis to analyze the potential role of algae within the pond system. Concurrent water quality sampling for selected metals in dissolved, acid soluble, and total forms would yield valuable information regarding algal pH control.

4.4.4 Pond Sediment Characterization

Fourteen pond bottom sediment samples were taken from the Warm Springs Ponds during the RI. The analytical results indicate very high total metals concentrations. Accurate determination of the degree and extent of sediment contamination is necessary information when developing clean-up alternatives; systematic sampling of the pond sediments is necessary to determine both the volume of sediments and the variation of metals concentrations with depth. Core samples should be obtained that show the vertical extent of the sediments. This characterization is recommended only if the removal of these sediments is being seriously considered as a remedial option.

4.4.5 Geochemical Computer Modelling

More rigorous analysis of mechanisms and/or the metal-phase distributions within the ponds may be useful for the feasibility study. Several computer modeling codes are available for determining geochemical equilibria and should be employed if necessary. Additional data would be required for input to most of these programs (e.g., Eh measurements).

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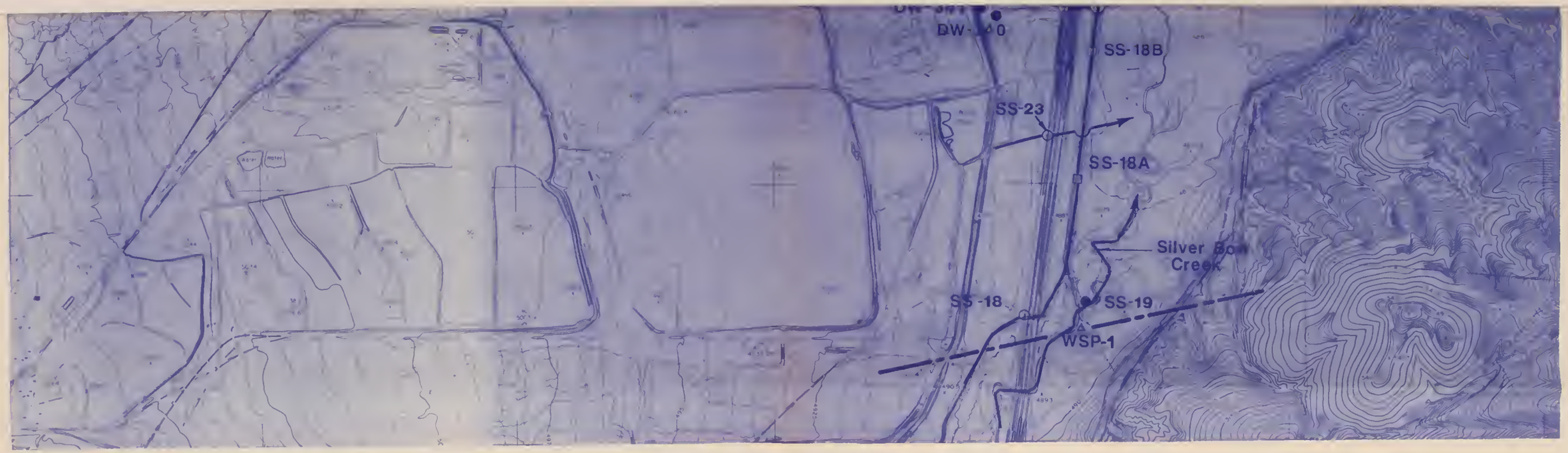
Clark Fork River
DW-407
WSP-5
WSP-4
WSP-3
SS-28
SS-25
DW-405
DW-406
PS-12
WSP-2
Warm Springs Creek
SS-18B
SS-27A
2
Pond 1
PS-11A
3
SS-26
SS-27
SS-18D
1
DW-411
DW-414
Pond 2
DW-404
DW-403
DW-415
SS-22
Warm Springs Ponds
2
SS-20
SS-21
DW-416
DW-412
Mill – Willow Bypass
1
DW-401
SS-18C
Pond 3
Opportunity Ponds
SS-24



LEGEND

- ○ SURFACE WATER SAMPLE SITE
- ● PERMANENT GAGE SITE AND SURFACE WATER SAMPLE SITE
- ▲ POINT SOURCE SAMPLE SITE
- □ SEEPAGE SURFACE WATER SAMPLE SITE
- ◪ POND BOTTOM SAMPLE SITE
- △ SILVER BOW CREEK RI MONITORING WELL
- ⬢ EXISTING MONITORING WELL
- ◓ DOMESTIC WELL

0 2000

SILVER BOW CREEK
REMEDIAL INVESTIGATION
MAP 1-2
WARM SPRINGS PONDS

WARM SPRINGS POND No. 2

CONTROL PT
0+00
ELE. 4835.69

CONTROL PT
4+18.73
ELE. 4836.1

CONTROL PT.
10+00
ELE. 4837.00'

CONTROL PT.
43+91.38
ELE. 4838.8'

CONTROL PT
60+00
ELE. 4844

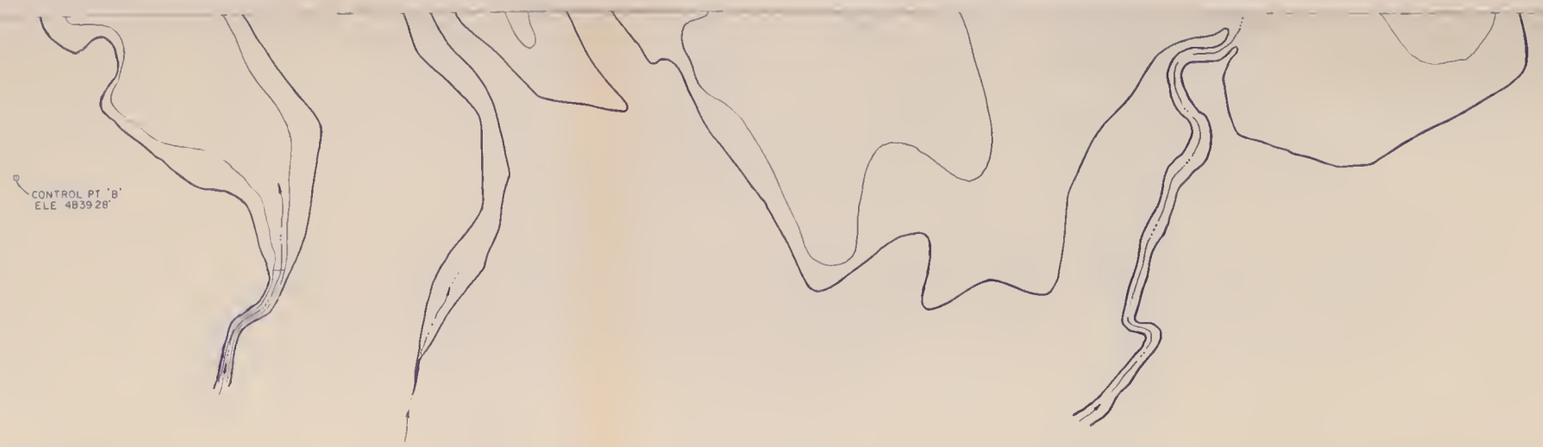
CONTROL PT C
ELE 4841.00

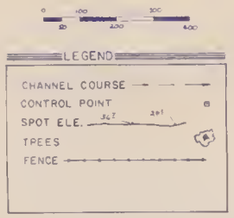
CONTROL PT. A
ELE. 4837.00

NOTE: DIKE IS REPRESENTED BY A LINE MARKING THE TOP OF THE INSIDE SLOPE & A LINE MARKING THE EDGE OF THE WATER. SPOT ELEVATIONS ARE GIVEN FOR THE TOP EDGE.

(TOP OF WATER ELEVATION = 4831.90
JAN. 25, 1985)

N





DATUM: B 314 1959 USC&GS BM 4839.22

SILVER BOW CREEK
REMEDIAL INVESTIGATION

MAP 2-1

CASHELL ENGINEERS
1130 EAST FRONT ST. - P.O. BOX 3587
(406) 723-7395 BUTTE, MT. 59701

REMEDIAL INVESTIGATION for SILVER BOW CREEK

WARM SPRINGS POND No. 2 (Site map)

DR. BY. H.E.	CK BY
SCALE: 1"= 200'	PROJ. No. 848173SILV
DATE: 1-5-15	SHT. No. of

WARM SPRINGS POND No. 3

NOTE: DIKE IS REPRESENTED BY A LINE MARKING THE TOP OF THE INSIDE SLOPE AND A LINE MARKING THE EDGE OF THE WATER.

SPOT ELEVATIONS ARE SHOWN FOR THE TOP EDGE.

0+00.00
4872.14

DECANT TOWER

— DIKE —

34+07.22

DECANT TOWER

63+31.36
4870.47

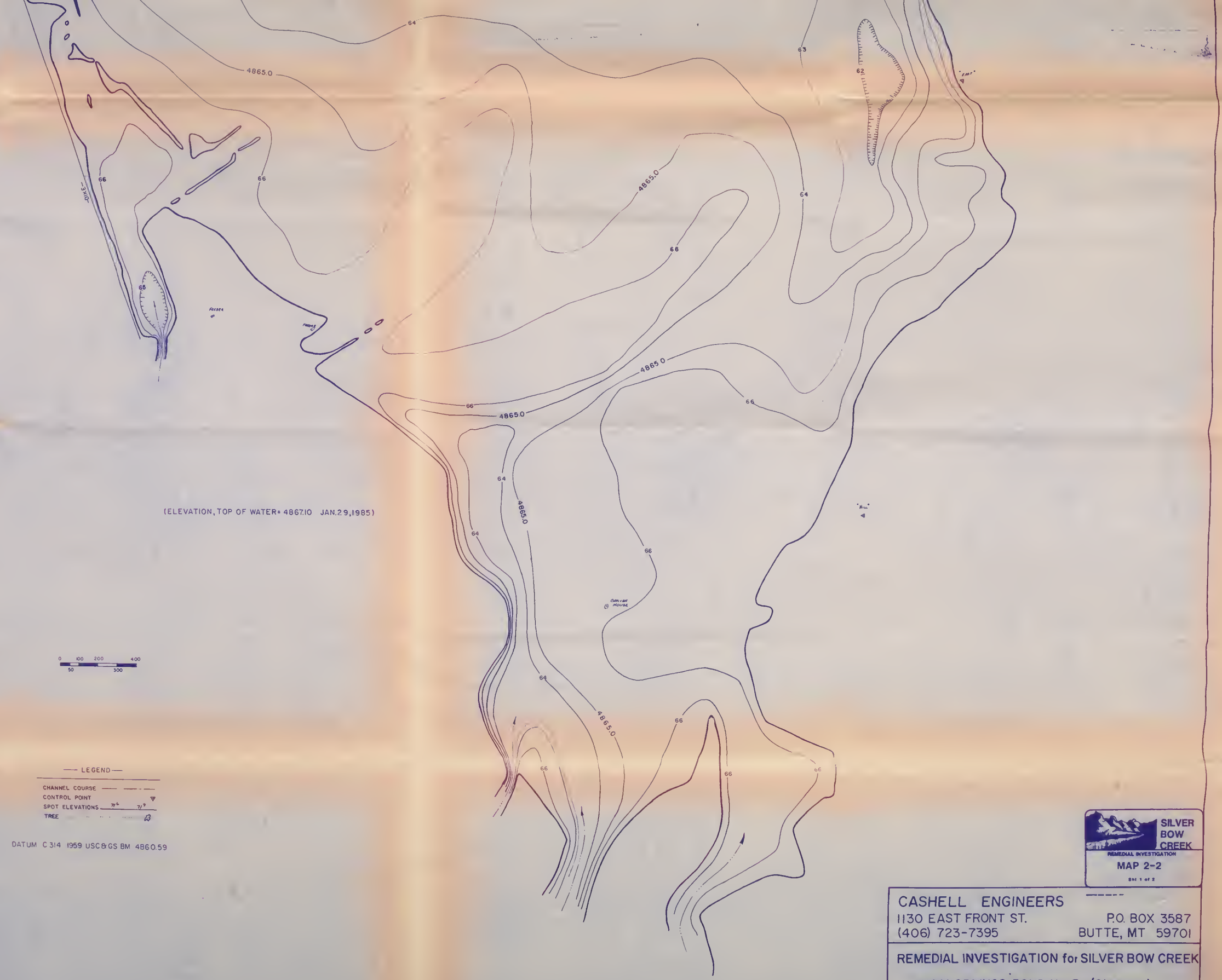
48500

48550

4860.0

4865.0

SILVER BOW CREEK
REMEDIAL INVESTIGATION
MAP 2-2
SHT 2 of 2



(ELEVATION, TOP OF WATER = 4867.10 JAN. 29, 1985)

0 100 200 400
50 300

— LEGEND —

CHANNEL COURSE
CONTROL POINT
SPOT ELEVATIONS 71.6 71.9
TREE

DATUM C 314 1959 USC&GS BM 4860.59

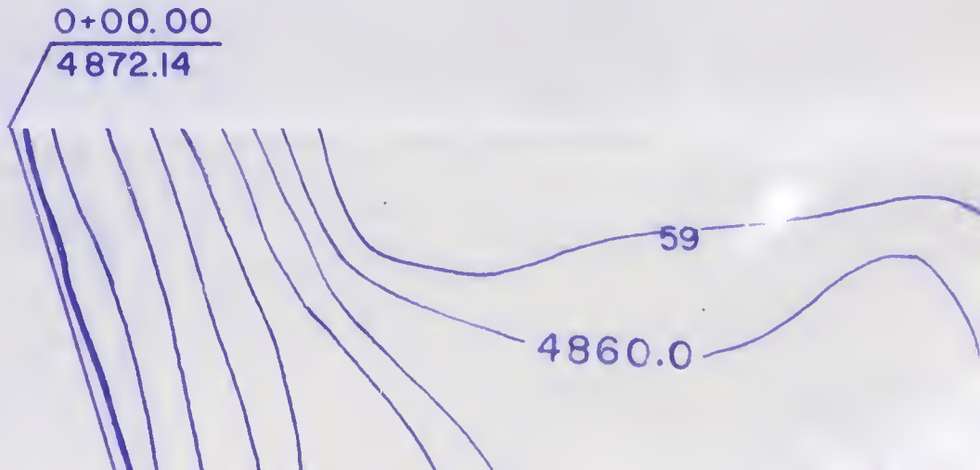
SILVER BOW CREEK
REMEDIAL INVESTIGATION
MAP 2-2
Sht 1 of 2

CASHELL ENGINEERS
1130 EAST FRONT ST. P.O. BOX 3587
(406) 723-7395 BUTTE, MT 59701

REMEDIAL INVESTIGATION for SILVER BOW CREEK

WARM SPRINGS POND No. 3 (Site map)

DR BY	CK BY
SCALE: 1" = 200'	PROJ. No. 848 173 SILV
DATE Apr 15, 1985	SHT No of


0+00.00
4872.14
59
4860.0